



**VOLUME THREE**

MERRILL'S ATLAS  
*of*

**RADIOGRAPHIC  
POSITIONS  
&  
RADIOLOGIC  
PROCEDURES**

Tenth Edition

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# CENTRAL NERVOUS SYSTEM

PAULA PATE-SCHLODER

Lumbar myelogram: AP projection with non-water-soluble iodinated contrast medium, showing axillary pouches and corresponding nerve roots (*arrow*).



## OUTLINE

### ANATOMY, 2

Brain, 2

Spinal cord, 3

Meninges, 3

Ventricular system, 4

### RADIOGRAPHY, 5

Plain radiographic examination, 5

Myelography, 6

Computed tomography, 10

Magnetic resonance imaging, 12

Cardiovascular and interventional procedures, 13

Other neuroradiographic procedures, 15

Definition of terms, 18



For descriptive purposes, the central nervous system (CNS) is divided into two parts: (1) the *brain*\*, which occupies the cranial cavity, and (2) the *spinal cord*, which is suspended within the vertebral canal.

\*Many italicized words are defined at the end of the chapter.

## Brain

The brain is composed of an outer portion of gray matter called the *cortex* and an inner portion of *white matter*. The brain consists of the *cerebrum*, the *cerebellum*, and the *brainstem*, which is continuous with the spinal cord (Fig. 25-1). The brainstem consists of the *midbrain*, *pons*, and *medulla oblongata*.

The cerebrum is the largest part of the brain and is referred to as the *forebrain*. Its surface is convoluted by sulci and grooves that divide it into lobes and lobules. The stemlike portion that connects the cerebrum to the pons and cerebellum is termed the *midbrain*. The cerebellum, pons, and medulla oblongata make up the *hindbrain*.

A deep cleft, called the *longitudinal sulcus* (interhemispheric fissure), separates the cerebrum into *right* and *left hemispheres*, which are closely connected by bands of nerve fibers, or commissures. The largest commissure between the cerebral hemispheres is the *corpus callosum*. The corpus callosum is a midline structure inferior to the longitudinal sulcus. Each cerebral hemisphere contains a fluid-filled cavity called a *lateral ventricle*. At the diencephalon, or second portion of the brain, the thalami surround the *third ventricle*. Inferior to the diencephalon is the *pituitary gland*; the master endocrine gland of the body. The pituitary gland resides in the hypophyseal fossa of the sella turcica.

The cerebellum, the largest part of the hindbrain, is separated from the cerebrum by a deep transverse cleft. The hemispheres of the cerebellum are connected by a median constricted area called the *vermis*. The surface of the cerebellum contains numerous transverse sulci that account for its cauliflower appearance. The tissues between the curved sulci are called *folia*. The pons, which forms the upper part of the hindbrain, is the commissure or bridge between the cerebrum, cerebellum, and medulla. The medulla, which extends between the pons and spinal cord, forms the lower portion of the hindbrain. All the fiber tracts between the brain and spinal cord pass through the medulla.

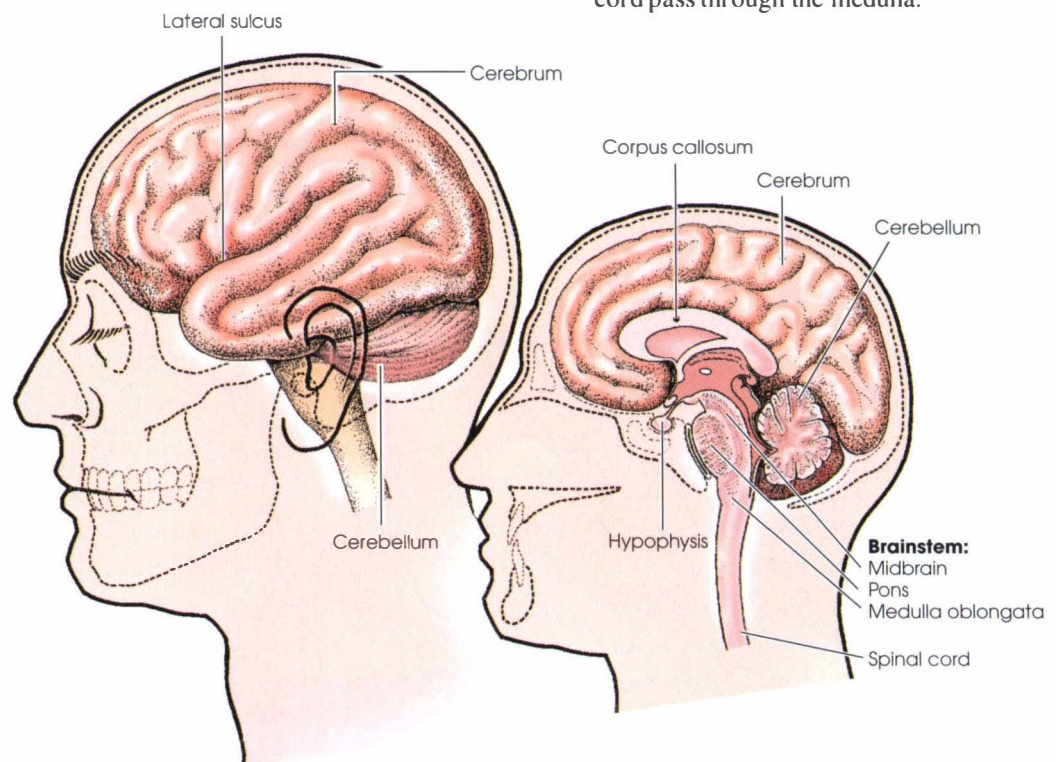


Fig. 25-1 Lateral surface and midsection of brain.



## Spinal Cord

The *spinal cord* is a slender, elongated structure consisting of an inner, gray, cellular substance, which has an H shape on transverse section, and an outer, white, fibrous substance (Figs. 25-2 and 25-3). The cord extends from the brain, where it is connected to the medulla oblongata at the level of the foramen magnum, to the approximate level of the space between the first and second lumbar vertebrae. The spinal cord ends in a pointed extremity called the *conus medullaris*. The *filum terminale* is a delicate, fibrous strand that extends from the terminal tip and attaches the cord to the upper coccygeal segment.

The spinal cord is connected to 31 pairs of spinal nerves, each arising from two roots at the sides of the spinal cord. The nerves are transmitted through the intervertebral and sacral foramina. Spinal nerves below the termination of the spinal cord extend inferiorly through the vertebral canal. These nerves resemble a horse's tail and are referred to as the *cauda equina*. The spinal cord and nerves work together to transmit and receive sensory, motor, and reflex messages to and from the brain.

## Meninges

The brain and spinal cord are enclosed in three continuous, protective membranes called *meninges*. The inner sheath, called the *pia mater* (Latin, "tender mother"), is highly vascular and closely adherent to the underlying brain and cord structure.

The delicate central sheath is called the *arachnoid*. This membrane is separated from the pia mater by a comparatively wide space called the *subarachnoid space*, which is widened in certain areas. These areas of increased width are called *subarachnoid cisterns*. The widest area is the cisterna magna (cisterna cerebellomedullaris). This triangular cavity is situated in the lower posterior fossa between the base of the cerebellum and the dorsal surface of the medulla oblongata. The subarachnoid space is continuous with the ventricular system of the brain and communicates with it through the foramina of the fourth ventricle. The ventricles of the brain and the subarachnoid space contain *cerebrospinal fluid* (CSF). CSF is the tissue fluid of the brain and spinal cord; it surrounds and cushions the structures of the central nervous system.

The outermost sheath, called the *dura mater* (Latin, "hard mother"), forms the strong, fibrous covering of the brain and spinal cord. The dura is separated from the arachnoid by the *subdural space* and from the vertebral periosteum by the *epidural space*. These spaces do not communicate with the ventricular system. The dura mater is composed of two layers throughout its cranial portion. The outer layer lines the cranial bones, thus serving as periosteum to their inner surface. The inner layer protects the brain and supports the blood vessels. The layer also has four partitions that provide support and protection for the various parts of the brain. One of these partitions, the *falx cerebri*, runs through the interhemispheric fissure and provides support for the cerebral hemispheres. The *tentorium* is a tent-shaped fold of dura that separates the cerebrum and cerebellum. Changes in the normal positions of these structures often indicate pathology. The dura mater extends below the spinal cord (to the level of the second sacral segment) to enclose the spinal nerves, which are prolonged inferiorly from the cord to their respective exits. The lower portion of the dura mater is called the *dural sac*. The cauda equina is enclosed by the dural sac.

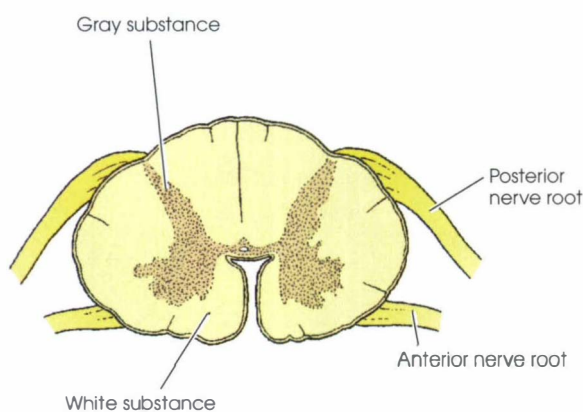


Fig. 25-2 Transverse section of spinal cord.

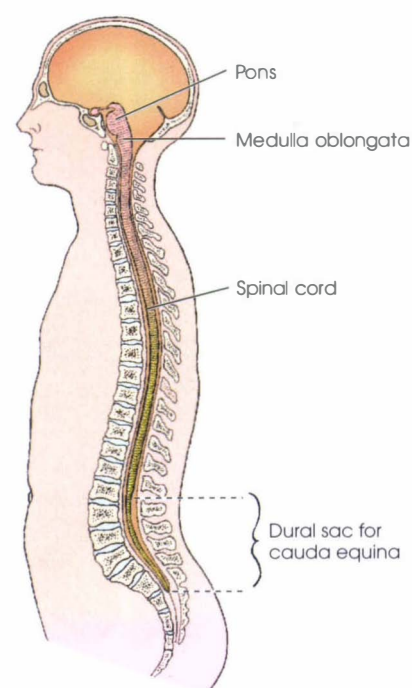


Fig. 25-3 Sagittal section showing spinal cord.

## Ventricular System

The ventricular system of the brain consists of four irregular, fluid-containing cavities that communicate with one another through connecting channels (Figs. 25-4 to 25-6). The two upper cavities are an identical pair and are simply called the *right* and *left lateral ventricles*. They are situated, one on each side of the midsagittal plane, in the inferior medial part of the corresponding hemisphere of the cerebrum.

Each lateral ventricle consists of a central portion called the *body* of the cavity. The body is prolonged anteriorly, posteriorly, and inferiorly into hornlike portions that give the ventricle an approximate U shape. The prolonged portions are known as the *anterior*, *posterior*, and *inferior horns*. Each lateral ventricle is connected to the third ventricle by a channel called the *interventricular foramen* or foramen of Monroe, through which it communicates directly with the third ventricle and indirectly with the opposite lateral ventricle.

The *third ventricle* is a slitlike cavity with a somewhat quadrilateral shape. It is situated in the midsagittal plane just inferior to the level of the bodies of the lateral ventricles. This cavity extends anteroinferiorly from the pineal gland, which produces a recess in its posterior wall, to the optic chiasm, which produces a recess in its anteroinferior wall.

The *interventricular foraminae*, one from each lateral ventricle, open into the anterosuperior portion of the third ventricle. The cavity is continuous posteroinferiorly with the fourth ventricle by a passage known as the *cerebral aqueduct* or aqueduct of Sylvius.

The *fourth ventricle* is diamond shaped and is located in the area of the hindbrain. It is anterior to the cerebellum and posterior to the pons and the upper portion of the medulla oblongata. The distal, pointed end of the fourth ventricle is continuous with the central canal of the medulla oblongata. Cerebrospinal fluid exits the fourth ventricle into the subarachnoid space via the *median aperture* (foramen of Magendie) and the *lateral apertures* (foramen Lushka).

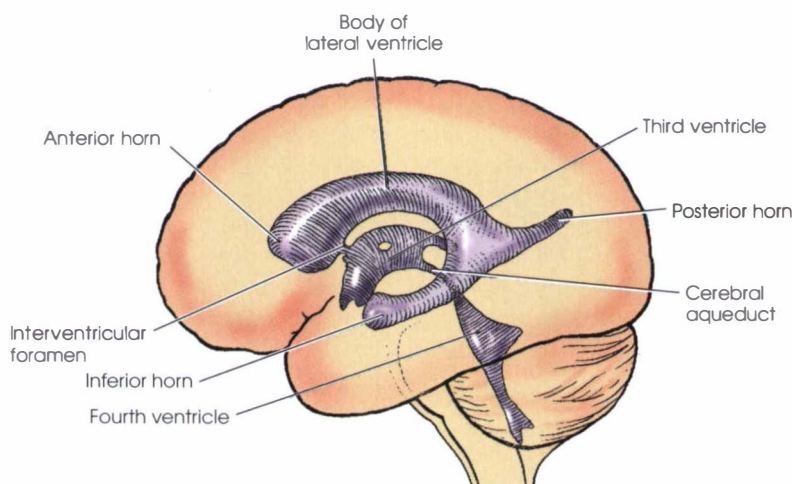


Fig. 25-4 Lateral aspect of cerebral ventricles in relation to surface of brain.

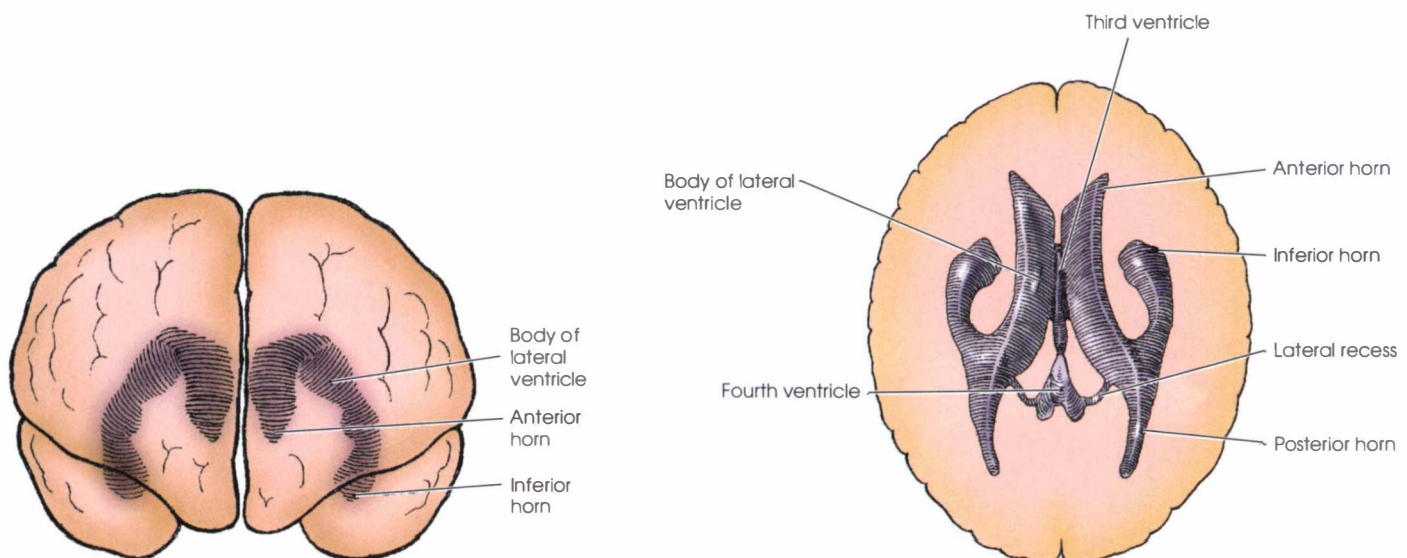


Fig. 25-5 Anterior aspect of lateral cerebral ventricles in relation to surface of brain.

Fig. 25-6 Superior aspect of cerebral ventricles in relation to surface of brain.



## Plain Radiographic Examination

Neuroradiologic assessment should begin with noninvasive imaging procedures. Radiographs of the cerebral and visceral cranium and the vertebral column may be employed to demonstrate bony anatomy. In traumatized patients (see Chapter 5), radiographs are obtained to detect bony injury, subluxation, or dislocation of the vertebral column and to determine the extent and stability of the bony injury.

For a traumatized patient with possible CNS involvement, a cross-table lateral cervical spine radiograph should be obtained first to rule out fracture or misalignment of the cervical spine. Approximately two thirds of significant pathologic conditions affecting the spine can be detected on this initial image. Care must be taken to demonstrate the entire cervical spine adequately, including the C7-T1 articulation. It may be necessary to employ the Twining (Swimmers) method (see Chapter 8) to demonstrate this anatomic region radiographically.

After the cross-table lateral radiograph has been checked and cleared by a physician, the following cervical spine projections should be obtained: an AP, bilateral AP oblique (trauma technique may be necessary), and an AP to demonstrate the dens. A vertebral arch, or pillar image, of the cervical spine may provide additional information about the posterior portions of the cervical vertebrae (see Chapter 8). An upright lateral cervical spine radiograph may also be requested to better demonstrate alignment of the vertebrae and to assess the normal lordotic curvature of the spine.

Tomography may be used to supplement images of the spine for initial screening purposes (see Chapter 32). However, tomography has been largely replaced by computed tomography (CT) in many institutions (see Chapter 33). Tomography may be employed to demonstrate long, continuous areas of the spine. Disadvantages of tomography include the lack of soft tissue detail and the difficulty in positioning a traumatized patient for lateral tomographic radiographs.

Radiographs of the spine should always be obtained before myelography. Routine images of the vertebral column are helpful in assessing narrowed disk spaces because of degeneration of the disk, postoperative changes in the spine, and osteopetrosis of the vertebral column. Because the contrast agents used in myelography may obscure some anomalies, non-contrast spinal images complement the myelographic examination and often provide additional information.

Routine skull images should be obtained when the possibility of a skull fracture exists. In trauma patients a cross-table lateral or upright lateral skull radiograph must be obtained to demonstrate air-fluid levels in the sphenoid sinus. In many instances these air-fluid levels may be the initial indication of a basilar skull fracture. In addition, skull images are helpful in diagnosing reactive bone formation and general alterations in the skull resulting from a variety of pathologic conditions, including Paget's disease, fibrous dysplasia, hemangiomas, and changes in the sella turcica.

## Myelography

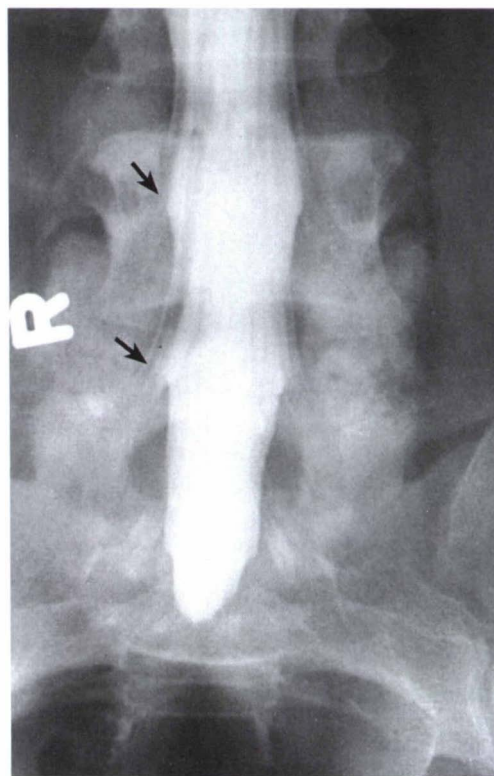
*Myelography* (Greek, myelos, “marrow; the spinal cord”) is the general term applied to radiologic examination of the CNS structures situated within the vertebral canal. This examination is performed by introducing a contrast medium into the subarachnoid space by spinal puncture, most commonly at the L2-L3 or L3-L4 interspace or at the cisterna magna between C1 and the occipital bone.

Most myelograms are performed on an outpatient basis, with patients recovering for approximately 4 to 8 hours after the procedure before being released to return home. In many parts of the country, however, magnetic resonance imaging (MRI) (see Chapter 36) has largely replaced myelography. Myelography continues to be the preferred examination method for assessing disk disease in patients with contraindications to MRI such as pacemakers or metallic posterior spinal fusion rods.

Myelography is employed to demonstrate extrinsic spinal cord compression caused by a herniated disk, bone fragments, or tumors, as well as spinal cord swelling resulting from traumatic injury. These encroachments appear radiographically as a deformity in the subarachnoid space or an obstruction of the passage of the column of contrast medium within the subarachnoid space. Myelography is also useful in identifying narrowing of the subarachnoid space by evaluating the dynamic flow patterns of the CSF.

## CONTRAST MEDIA

A nonwater-soluble, iodinated ester (iopendylate [Pantopaque]) was introduced in 1942. Because it could not be absorbed by the body, this lipid-based contrast medium required removal post procedure. Frequently some contrast remained in the canal and can be seen on non-contrast radiographs of patients who had the myelography procedure before the introduction of the newer medium. Iopendylate was used in myelography for many years but is no longer commercially available. The first water-soluble, nonionic, iodinated contrast agent, metrizamide, was introduced in the late 1970s. Thereafter, water-soluble contrast media quickly became the agents of choice. Nonionic, water-soluble contrast media provide good visualization of nerve roots (Fig. 25-7) and good enhancement for follow-up CT of the spine. In addition, these agents are readily absorbed by the body. One disadvantage of metrizamide was its tendency to be absorbed very quickly. Therefore radiographs were required to be produced promptly and accurately.



**Fig. 25-7** Myelogram using water-soluble contrast medium (metrizamide). Nerve roots seen at arrows.



Further research led to the introduction of improved nonionic water soluble contrast agents such as iohexol, iopamidol, and ioversol in the mid 1980s. Improvements in nonionic contrast agents have resulted in fewer side effects. Consequently, they have become the preferred contrast media for both conventional and CT myelography (Fig. 25-8).

### PREPARATION OF EXAMINING ROOM

One of the radiographer's responsibilities is to prepare the examining room before the patient's arrival. The radiographic equipment should be checked. Because the procedure involves aseptic technique, the table and overhead equipment must be cleaned. The footboard should be attached to the table, and the padded shoulder supports should be placed and ready for adjustment to the patient's height. The image intensifier should be locked so that it cannot accidentally come in contact with the spinal needle and/or sterile field.

The spinal puncture and contrast medium injection are performed in the radiology department. Under fluoroscopic observation, placement of the 20- to 22-gauge spinal needle in the subarachnoid space is verified, and the contrast medium is injected. The sterile tray and the non-sterile items required for this initial procedure should be ready for convenient placement.



**Fig. 25-8** Lateral projection of lumbar spine myelogram using water-soluble contrast medium (iohexol).

## EXAMINATION PROCEDURE

Premedication of the patient for myelography is rarely necessary. The patient should be well hydrated, however, because a non-ionic, water-soluble contrast medium is used. To reduce apprehension and prevent alarm at unexpected maneuvers during the procedure, the radiographer should explain the details of myelography to the patient before the examination begins. The patient should be informed that the angulation of the examining table will repeatedly and acutely change. The patient should also be told why the head must be maintained in a fully extended position when the table is tilted to the Trendelenburg position. The radiographer must provide assurance that the patient will be safe when the table is acutely angled and that everything possible will be done to avoid causing unnecessary discomfort.

Scout images, including a cross table lateral lumbar spine prone, are often requested. Some physicians prefer to have the patient placed on the table in the prone position for the spinal puncture. Many, however, have the patient adjusted in the lateral position with the spine flexed to widen the interspinous spaces for easier introduction of the needle.

The physician usually withdraws CSF for laboratory analysis and slowly injects approximately 9 to 12 ml of contrast medium. After completing the injection, the physician removes the spinal needle. Travel of the contrast medium column is observed and controlled fluoroscopically. Angulation of the table allows gravity to direct the contrast to the area of interest. Spot images are taken throughout the procedure. The radiographer obtains images at the level of any blockage or distortion in the outline of the contrast column. Conventional radiographic studies, with the central ray directed vertically or horizontally, may be performed as requested by the radiologist. The *conus projection* is

used to demonstrate the *conus medullaris*. For this the patient is placed in the AP position with the central ray centered to T12-L1. A 24 × 30 cm (10 × 12 inch) cassette is used. Cross-table lateral radiographs are obtained with grid-front cassettes or a stationary grid; they must be closely collimated (Figs. 25-9 to 25-13).

The position of the patient's head must be guarded as the contrast column nears the cervical area to prevent the medium from passing into the cerebral ventricles. Acute extension of the head compresses the cisterna magna and thus prevents further ascent of the medium. Because the cisterna magna is situated posteriorly, neither forward nor lateral flexion of the head compresses the cisternal cavity.

After completion of the procedure the patient must be monitored in an appropriate recovery area. Most physicians recommend that the patient's head and shoulders be elevated 30 to 45 degrees during recovery. Bed rest for several hours is recommended and fluids are encouraged. The puncture site must be examined before the patient is released from the recovery area.

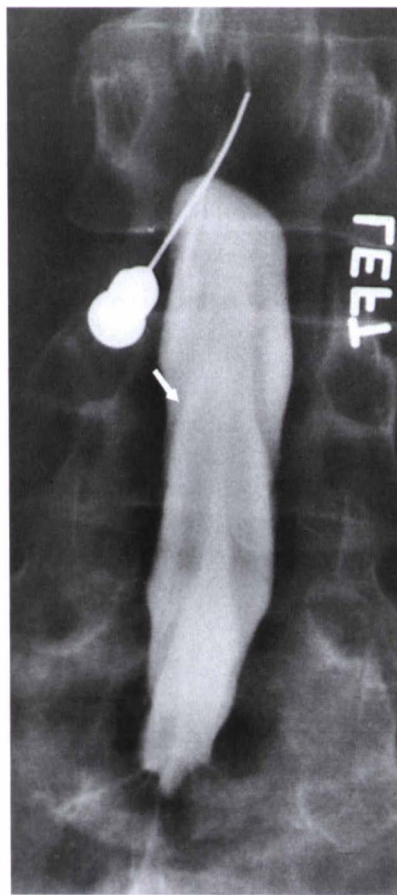


Fig. 25-9 Lumbar myelogram: AP projection with non-water-soluble iodinated contrast medium, showing axillary pouches and corresponding nerve roots (arrow).

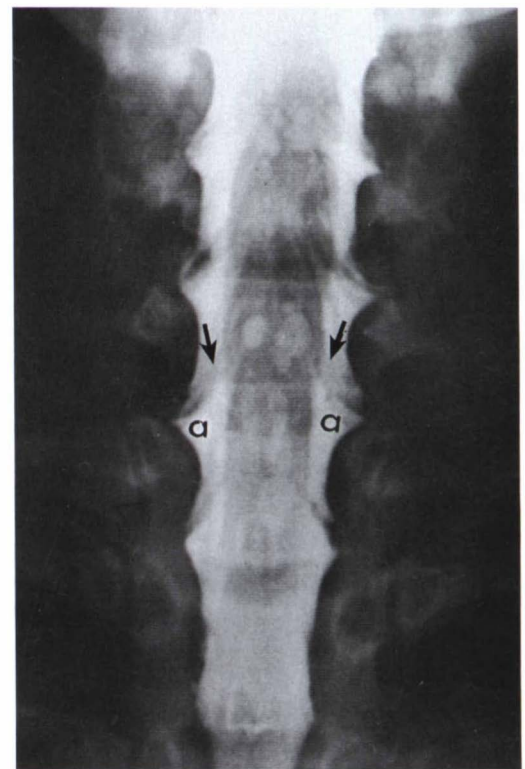


Fig. 25-10 Cervical myelogram: AP projection showing symmetric nerve roots (arrows) and axillary pouches (a) on both sides, as well as spinal cord.





Fig. 25-11 Myelogram: prone cross-table lateral projection showing dentate ligament and posterior nerve roots (*arrow*).

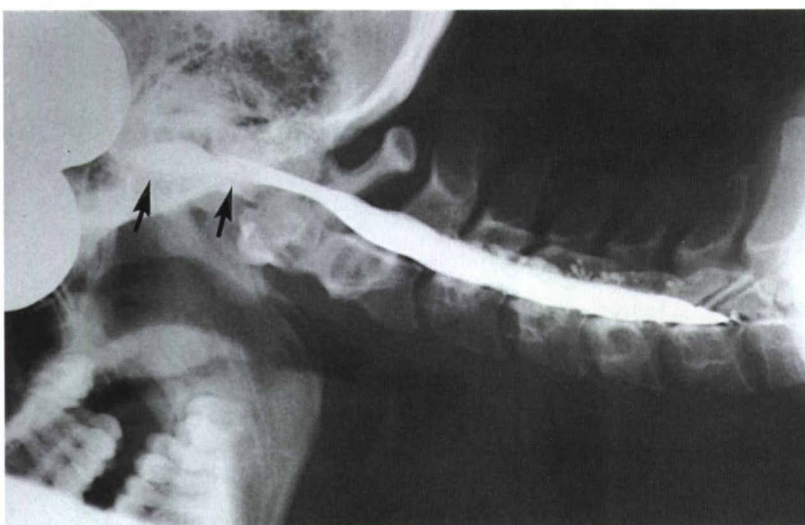


Fig. 25-12 Myelogram: prone, cross-table lateral projection showing contrast medium passing through foramen magnum and lying against lower clivus (*arrows*).

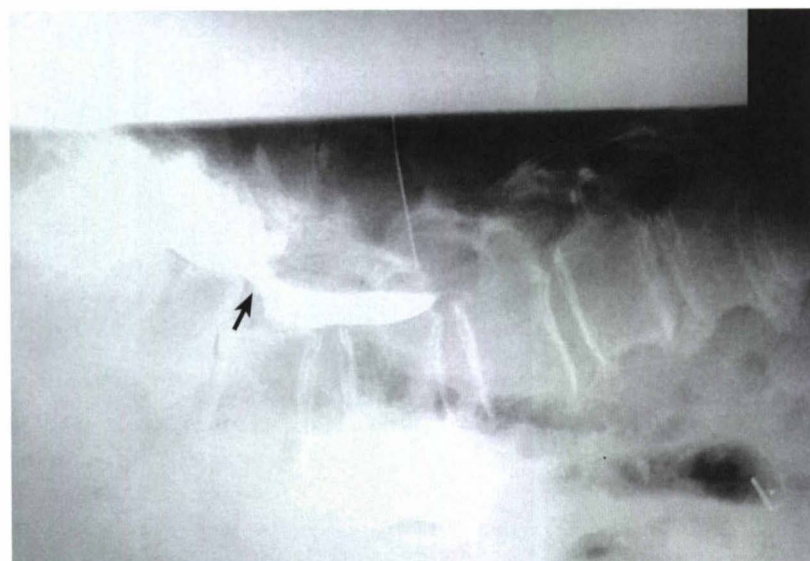


Fig. 25-13 Myelogram: cross-table lateral projection showing subarachnoid space narrowing (*arrow*).

## Computed Tomography

CT is a rapid, noninvasive imaging technique that was first introduced for clinical use in the early 1970s. It produces sectional images of the brain called *slices*. CT imaging of the head and spine expanded rapidly because of improvements in computer technology and this imaging modality's ability to demonstrate abnormalities with a precision never before possible. Digital image processing techniques in CT allow for changes in the density and contrast of an image, called *windowing*. The use of different windows allows for visualization of both soft tissue and bony structures. (See Chapter 33 for more detail.)

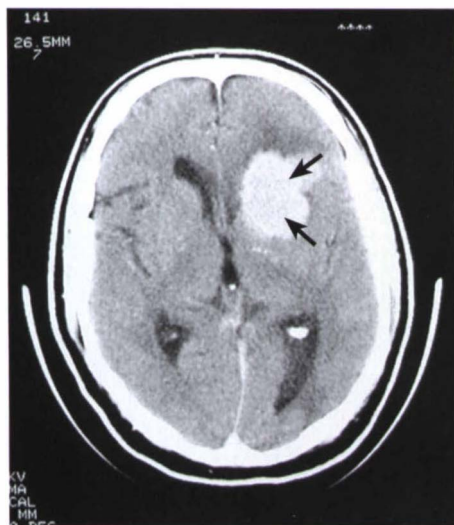


Fig. 25-14 Postinfusion (C1) CT scan of the brain, demonstrating a tumor "highlighted" by the IV contrast material (arrows).



Fig. 25-15 CT scan of the brain (C2) demonstrating a giant berry aneurysm (arrows) later confirmed by vascular imaging.

A CT examination of the brain is commonly performed in an axial orientation with the gantry placed at an angle of 20 to 25 degrees to the orbitomeatal line, which allows the lowest slice to provide an image of both the upper cervical/foramen magnum and the roof of the orbit. Normally 12 to 14 slices are obtained, depending on the size of the patient's head and the thickness of the CT image slices. Imaging continues superiorly until the entire head has been examined. A slice thickness of 8 to 10 mm is often used, but most institutions utilize 3 to 5 mm slices through the area of the posterior fossa. Coronal images may also be obtained and are quite helpful in evaluating abnormalities of the pituitary gland and sella turcica, as well as facial bones and sinuses. The computer may be used to reconstruct and display the images in a variety of imaging planes.

CT scans of the brain are often obtained before and after IV injection of a nonionic, water-soluble contrast agent. These are often referred to as *preinfusion* (C-) and *postinfusion* (C+) scans. Common indications for scans with and without contrast agents include suspected primary neoplasms (Fig. 25-14); suspected metastatic disease; suspected arteriovenous malformation (AVM); demyelinating disease such as multiple sclerosis; seizure disorders; and bilateral, isodense hematomas. Common indications for CT of the brain without an IV infusion of contrast material include assessment of dementia, craniocerebral trauma, hydrocephalus, and acute infarcts. In addition, CT is often used for postevacuation follow-up examinations of hematomas.



Fig. 25-16 Normal CT scan of the brain utilizing bone windows for fracture evaluation.



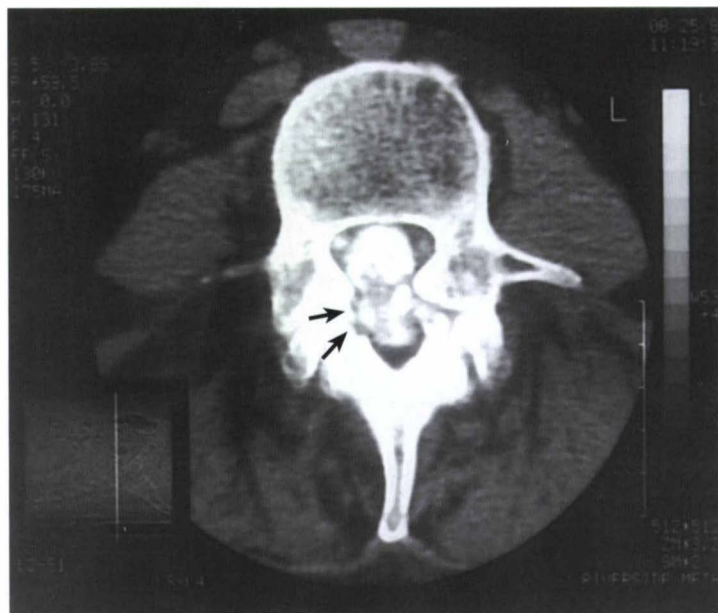
CT of the brain is particularly useful in demonstrating the size, location, and configuration of mass lesions, as well as surrounding edema. It is also quite helpful in assessing cerebral ventricle or cortical sulcus enlargement. Shifting of midline structures resulting from the encroachment of a mass lesion, cerebral edema, or a hematoma can be visualized without contrast media. CT of the head is also the imaging modality of choice in evaluating hematomas, suspected aneurysms (Fig. 25-15), ischemic or hemorrhagic strokes, and acute infarcts within the brain. CT of the brain is the initial diagnostic procedure performed to assess craniocerebral trauma, because it provides a very accurate diagnosis of acute intracranial injuries, such as brain contusions and subarachnoid hemorrhage. Bone windows are used for fracture evaluation on trauma patients (Fig. 25-16).

CT of the spine is helpful in diagnosing vertebral column hemangiomas and lumbar spinal stenosis. CT of the cervical spine following trauma is frequently performed to rule out fractures of the axis and atlas and to better demonstrate the lower cervical and upper thoracic vertebrae. This examination can clearly demonstrate the size, number, and location of fracture fragments in the cervical, thoracic, and lumbar spine. The information gained from the CT scans can greatly assist the surgeon (Fig. 25-17). Postoperatively, CT is used to assess the outcome of the surgical procedure.

Computed tomography myelography (CTM) involves CT examination of the vertebral column after the *intrathecal* injection of a water soluble contrast agent. The examination may be performed at any level of the vertebral column. Today most conventional myelograms are followed by CTM. Because CT has the ability to distinguish among relatively small differences in contrast, the contrast agent may be visualized up to 4 hours following the conventional myelogram. CTM demonstrates the size, shape, and position of the spinal cord and nerve roots (Fig. 25-18). It is extremely useful in patients with compressive injuries or in determining the extent of dural tears resulting in extravasation of the CSF. (CT is discussed further in Chapter 33.)



**Fig. 25-17** Sagittal CT lumbar spine: reconstruction of axial images showing a compression fracture of L3 subsequent to trauma (arrows).



**Fig. 25-18** CT myelogram of the lumbar spine demonstrating subarachnoid space narrowing (arrows).

## Magnetic Resonance Imaging

*MRI* was approved for clinical use in the early 1980s and quickly became the modality of choice for evaluating many anomalies of the brain and spinal cord. It is a noninvasive procedure that provides excellent anatomic detail of the brain, spinal cord, intervertebral disks, and CSF within the subarachnoid space. Furthermore, unlike conventional myelography, MRI of the spinal cord and subarachnoid space does not require intrathecal injection of a contrast agent. (MRI is discussed in Chapter 36.)

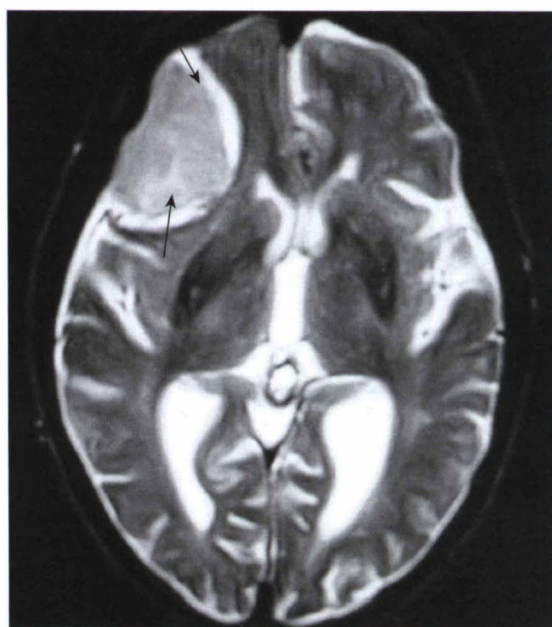
Because MRIs are created primarily by the response of loosely bound hydrogen atoms to the magnetic field, this modality is basically “blind” to bone, unlike other conventional radiologic imaging modalities. Therefore MRI allows clear visualization of areas of the CNS normally obscured by bone, such as the vertebral column and structures in the base of the skull. The exact relationship between soft tissue structures and surrounding bony structures can be seen (Fig. 25-19). This makes MRI the preferred modality in evaluating the middle cranial fossa and posterior fossa of the brain. When these structures are imaged with CT, they are often obscured by artifacts. MRI is also the preferred modality for evaluating the spinal cord because it allows direct visualization of the cord, nerve roots, and surrounding CSF. In addition, MRI reconstruction may be performed in a variety of planes (sagittal, axial, and coronal) after acquisition (Figs. 25-20 and 25-21) to aid in the diagnosis and treatment of neurologic disorders. Both T1- and T2-weighted images are obtained to assist in the diagnosis, with a head coil used for the brain and cervical spine images and a body coil used in combination with a surface coil for the remainder of the spine. Paramagnetic IV contrast agents such as Gadolinium are used to enhance tumor visualization.

MRI is very helpful in assessing demyelinating disease such as multiple sclerosis, spinal cord compression, paraspinal masses, postradiation therapy changes in spinal cord tumors, metastatic disease, herniated disks, and congenital anomalies of the vertebral column. In the brain, MRI is excellent for evaluating middle and posterior fossa abnormalities, acoustic neuromas, pituitary tumors, primary and metastatic neoplasms, hydrocephalus, AVMs, and brain atrophy.

Contraindications to MRI are primarily related to the use of a magnetic field. MRI should not be used in patients with pacemakers, ferromagnetic aneurysm clips, or metallic spinal fusion rods. In addition, MRI is of little value in assessing osseous bone abnormalities of the skull, intracerebral hematomas, and subarachnoid hemorrhage. CT provides better visualization of these pathologies.



**Fig. 25-19** Sagittal MRI section of the cervical spine demonstrating a marrow replacing lesion at C5 (arrow).



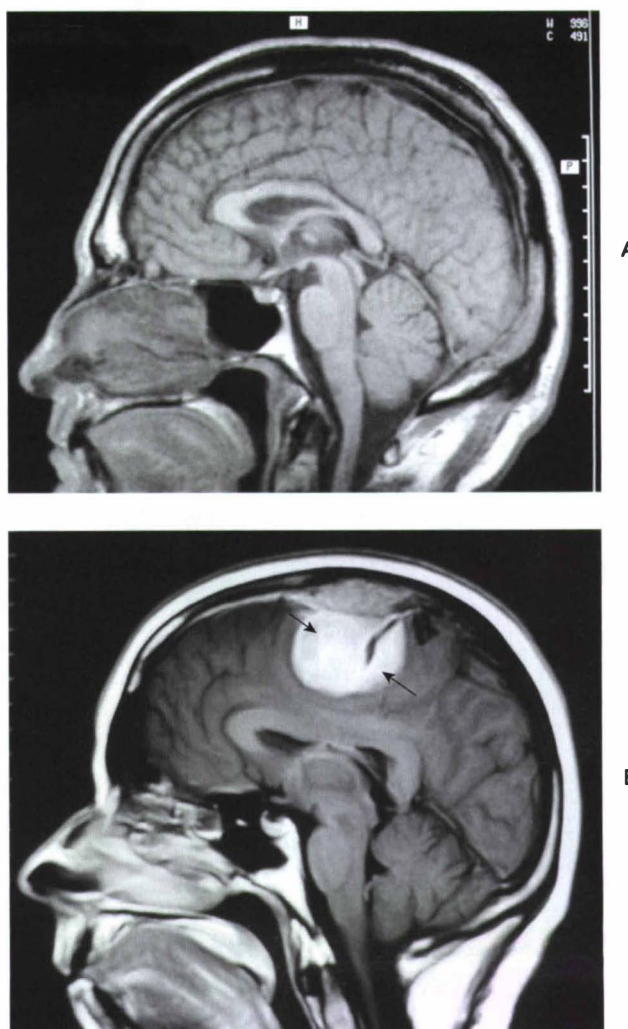
**Fig. 25-20** Axial MRI section through the brain demonstrating a right frontal lobe meningioma (arrows).



## Cardiovascular and Interventional Procedures

In general, cardiovascular and interventional procedures are performed after non-invasive evaluation techniques when it is necessary to obtain information about the vascular system or to perform an interventional technique. *Angiography* may be used to assess vascular supply to tumors, demonstrate the relationship between a mass lesion and intracerebral vessels, or illustrate anomalies of a vessel such as an aneurysm or a vascular occlusion. An angiographic procedure is performed in a specialized imaging suite under sterile conditions. (Cardiovascular and interventional radiology of the cerebral circulation is discussed in more detail in Chapter 26.)

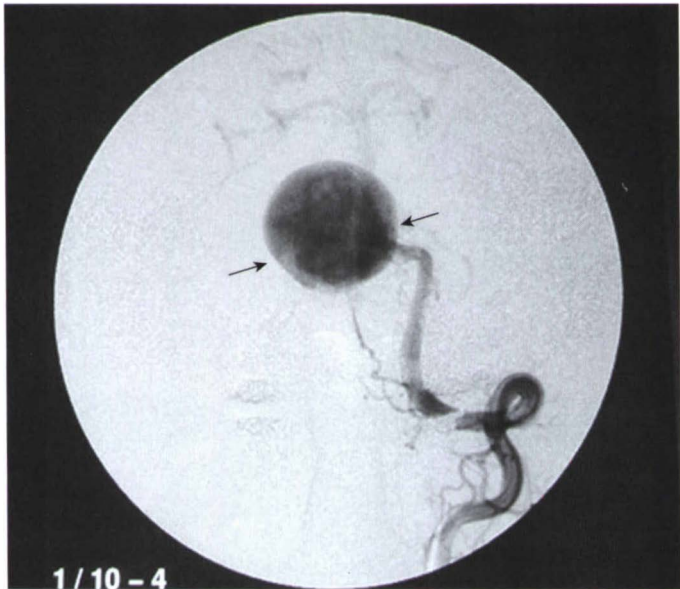
Cardiovascular and interventional imaging equipment requires multiplanar imaging and digital subtraction capabilities. Angiographic x-ray tubes should have a minimum focal spot size of 1.3 mm for routine imaging and a magnification focal spot size of 0.3 mm. The procedure requires the introduction of a catheter into the vascular system under fluoroscopic guidance. The image intensifier must be designed to move around the patient so that various tube angles may be obtained without moving the patient. The catheter is most commonly placed in the femoral artery; however, access may be gained using other arteries or veins, depending on the patient's clinical history and the area of interest. After the catheter is placed in the appropriate vessel, a water-soluble contrast agent is injected into the vessels, and rapid-sequence images are obtained for evaluation.



**Fig. 25-21** **A**, Normal sagittal MRI section through the brain. **B**, Sagittal MRI section demonstrating a large meningioma (arrows).

Angiography is helpful in assessing vascular abnormalities within the CNS such as arteriosclerosis, arteriovenous malformations, aneurysms (Fig. 25-22), subarachnoid hemorrhage, transient ischemic attacks, certain intracerebral hematomas, and cerebral venous thrombosis. It is also performed in combination with interventional techniques to assess the placement of devices before and after the procedures.

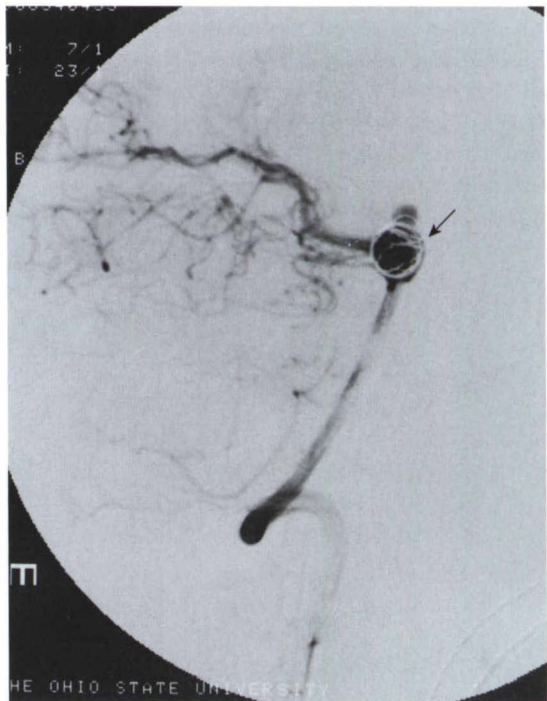
*Interventional radiology* involves the placement of various coils, medications, filters, or other devices to treat a particular problem or provide therapy. One type of interventional technique involves the introduction of small spheres, coils, or other materials into vessels to occlude blood flow. Embolization techniques are often performed to treat AVMs and aneurysms, and to decrease blood supply to various vascular tumors (Figs. 25-23 and 25-24). Other interventional techniques are used to open occluded vessels by the injection of specialized anticoagulant medications or by the inflation of small balloons within the vessel, as in the case of percutaneous angioplasty. In addition, therapeutic devices such as filters, stents, and shunts may be placed in the cardiovascular and interventional area, thereby eliminating the need for a more invasive surgical procedure.



**Fig. 25-22** Digital subtraction angiographic image demonstrating a large aneurysm of the basilar artery (arrows).



**Fig. 25-23** Conventional lateral skull projection demonstrating an embolization coil placed just posterior and superior to the sella turcica (arrow).



**Fig. 25-24** Digital subtraction angiographic image demonstrating an embolization coil (arrow), which has been placed to treat a basilar tip aneurysm.



## Other Neuroradiographic Procedures

*Diskography* and *nucleography* are terms used to denote the radiologic examination of individual intervertebral disks. The examination is performed with a small quantity of one of the water-soluble, iodinated media injected into the center of the disk by way of a double-needle entry. This procedure was introduced by Lindblom<sup>1</sup> in 1950, and it has been further detailed by Cloward and Buzaid,<sup>2</sup> Cloward,<sup>3</sup> and Butt.<sup>4</sup>

<sup>1</sup>Lindblom K: Technique and results in myelography and disc puncture, *Acta Radiol* 34:321, 1950.

<sup>2</sup>Cloward RB, Buzaid LL: Discography, *AJR* 68:552, 1952.

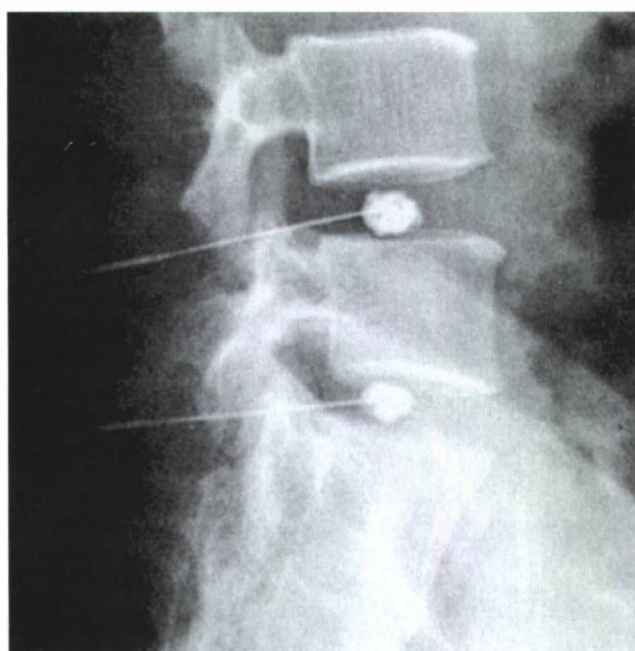
<sup>3</sup>Cloward RB: Cervical discography: a contribution to the etiology and mechanism of neck, shoulder, and arm pain, *Ann Surg* 150:1052, 1959.

<sup>4</sup>Butt WP: Discography—some interesting cases, *J Can Assoc Radiol* 17:167, 1966.

Diskography is used in the investigation of internal disk lesions, such as rupture of the nucleus pulposus, which cannot be demonstrated by myelographic examination (Fig. 25-25). Diskography may be performed separately, or it may be combined with myelography. Patients are given only a local anesthetic so that they remain fully conscious and therefore able to inform the physician about pain when the needles are inserted and the injection is made. MRI and CT myelography have largely replaced diskography. (More information on diskography is presented in Chapter 29 of the seventh edition of this Atlas.)

*Single photon emission computed tomography (SPECT)* is a nuclear medicine procedure used for demonstrating the brain. It requires an IV injection of a radionuclide that is taken up in the brain tissue and studied by a specialized SPECT camera. As with most nuclear medicine studies, this examination also assesses physiologic function instead of anatomic detail. It is useful in diagnosing seizure activity and ischemic or hemorrhagic strokes. (Further discussion of nuclear medicine is presented in Chapter 38.)

*Positron emission tomography (PET)* uses a very specialized imaging unit in combination with IV injection of a radionuclide to evaluate brain function by demonstrating metabolic activity within the brain. PET is gaining popularity for the evaluation of patients with suspected Alzheimer's disease, Huntington's disease, schizophrenia, and cocaine abuse. (Further discussion of positron emission tomography is presented in Chapter 40.)



**Fig. 25-25** Lumbar diskogram demonstrating normal nucleus pulposus of round contour type.

*Magnetic resonance angiography (MRA)* is an imaging technique that uses a conventional MRI unit to provide images of vessels within the body. Some clinicians believe that MRA is more accurate than conventional digital subtraction angiography in evaluating the carotid arteries and the circle of Willis within the brain. MRA does not require catheterization of a vessel or the injection of contrast material. Either venous or arterial vessels may be imaged. This technology takes advantage of the rapid laminar flow of blood within the vessels and is based on the intrinsic appearance of blood as it flows through the imaging slices. Blood travels so quickly that it does not stay in the scanning field long enough to return a signal back to the MRI coil. Using the correct MRI sequences results in a fairly clear image of the vessels of interest (Fig. 25-26). This imaging technique appears to be a promising tool for neuroradiology.

*Stereotactic surgery* and *stereotrophic surgery* are terms used to denote a highly specialized neurosurgical therapeutic technique for the precise three-dimensional guidance of a slender surgical instrument through a *burr hole* in the cranium to a predetermined point deep within the brain. The first practical stereotactic instrument was introduced in the late 1940s for use with pneumoencephalography. Stereotactic surgery is used in the treatment of various diseases of the nervous system, some of which cause loss of control of body movement and some of which cause intractable pain. The most frequent use of this surgical technique may be for the treatment of Parkinson's disease. It is also used to obtain biopsy specimens from deep tumors within the brain and to drain abscesses. Stereotactic surgery is often the preferred technique for the treatment of these conditions because the diseased structure can be reached and surgically destroyed with the slender, specialized instrument, thus eliminating the need for open surgery.

The tip of the surgical instrument must be placed in the target area with an accuracy of 1-mm deviation from the target point. This precise placement requires a specialized instrument guidance system known as a *stereotactic frame* or *stereotactic device*. Numerous types of stereotactic devices are currently in use. Basically, they consist of a frame that the surgeon uses to immobilize the patient's head with attached fixation screws. The frame incorporates an external reference system and an adjustable instrument device.



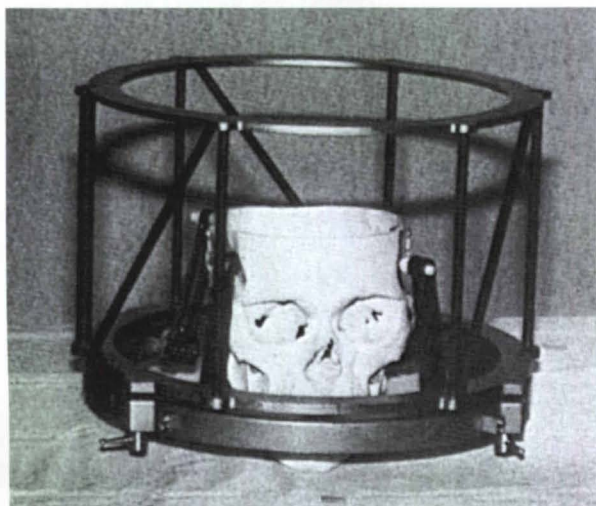
Fig. 25-26 MRA demonstrating a large middle cerebral artery aneurysm (arrow).



Stereotactic localization is currently performed with the assistance of CT. Early CT stereotactic devices used metal to fix the device to the skull, resulting in computer-generated artifacts on the CT image. Newer stereotactic devices contain carbon graphite posts and fine-metal skull pins surrounded by plastic bushings (Figs. 25-27 and 25-28). Computer programs are available that help to guide the needle for biopsy procedures. The data processing necessary to determine frame coordinates and probe depth can be performed with a programmable calculator. A software system transforms the two-dimensional coordinates obtained on the CT image to three-dimensional coordinates used by the surgeon. These coordinates are checked using a phantom simulator before the actual surgical procedure is performed.

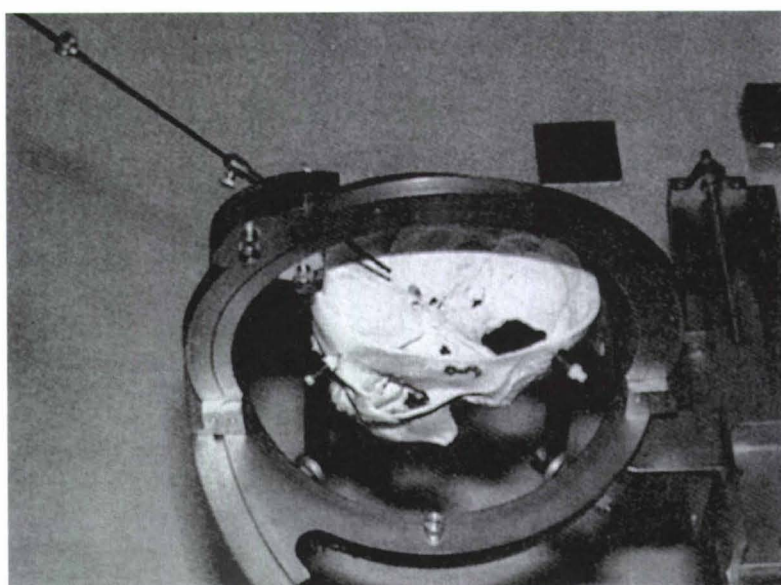
For the procedure a metal head ring is fixed to the skull with an attached localizing system consisting of three sets of vertical and diagonal rods. These rods are visible on the CT images and are used to determine spatial relationships. After the CT examination the patient is transported to the operating room, where the localizing rods are removed and replaced by an arc-guidance system to allow passage of the surgical instruments. The stereotactic frame is removed after the surgical procedure, and a postoperative CT examination may be performed to check the biopsy site. New devices are being developed that provide the same information without the use of a frame.

The use of MRI in conjunction with stereotactic surgery is still in its infancy. Stereotactic frames must have nonferromagnetic components, and they must be constructed so that eddy currents are not induced. The coordinate markers must be constructed of paramagnetic materials that are visualized on the MRI scans. MRI-assisted stereotactic procedures should prove useful for pathologic conditions that do not visualize well on CT images. Additional research on MRI applications is currently being conducted.



**Fig. 25-27** Localizing system attached to head ring.

(From Haaga JR: *Computed tomography*, St Louis, 1983, Mosby.)



**Fig. 25-28** Stereotactic instrument arc guidance system.

(From Haaga JR: *Computed tomography*, St Louis, 1983, Mosby.)

## Definition of Terms

**angiography** radiographic examination of the blood vessels after the injection of contrast medium

**arachnoid** a thin delicate membrane surrounding the brain and spinal cord

**brain** the portion of the central nervous system contained within the cranium

**cauda equina** a collection of nerves located in the spinal canal inferior to the spinal cord

**cerebellum** the part of the brain located in the posterior cranial fossa behind the brainstem

**cerebral aqueduct** an opening between the third and fourth ventricles

**cerebrospinal fluid** the fluid that flows through and protects the ventricles, subarachnoid space, brain and spinal cord

**cerebrum** the largest uppermost portion of the brain

**conus medullaris** the most inferior portion of the spinal cord

**cortex** the outer surface layer of the brain

**diskography** examination of intervertebral discs after the direct injection of contrast medium

**dura mater** the tough outer layer of the meninges which lines the cranial cavity and spinal canal

**epidural space** outside or above the dura mater

**falx cerebri** a fold of dura mater that separates the cerebral hemispheres

**filum terminale** a threadlike structure which extends from the distal end of the spinal cord

**gadolinium** an IV contrast medium used in MRI

**hindbrain** the portion of the brain within the posterior fossa; it includes the pons, medulla oblongata and cerebellum

**interventional radiology** a branch of radiology that uses catheters to perform therapeutic procedures

**intrathecal injection** an injection into the subarachnoid space of the spinal canal

**pons** an oval-shaped area of the brain anterior to the medulla oblongata

**slices** sectional images of the body produced with either computed tomography or magnetic resonance imaging

**spinal cord** an extension of the medulla oblongata that runs through the spinal canal to the upper lumbar vertebrae

**stereotactic surgery** a radiographic procedure performed during neurosurgery to guide needle placement into the brain

**tentorium** the layer of dura that separates the cerebrum and cerebellum

**vermis** a wormlike structure that connects the two cerebellar hemispheres

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# CIRCULATORY SYSTEM AND CARDIAC CATHETERIZATION

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Portal venogram. (*m*, Main portal v.;  
*s*, superior mesenteric v.; *i*, inferior  
mesenteric v.; *sp*, splenic v.; *c*, coronary  
varices.)

## OUTLINE

### ANATOMY, 20

Circulatory system, 20  
Blood-vascular system, 21  
Lymphatic system, 24

### ANGIOGRAPHY, 26

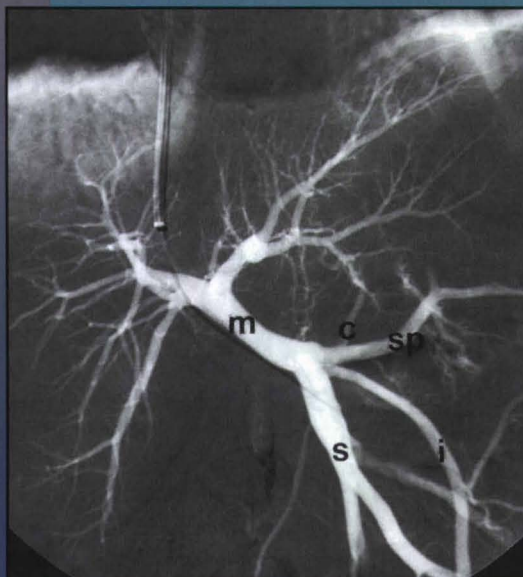
Definitions and indications, 26  
Historical development, 26  
Angiographic studies, 27

### AORTOGRAPHY, 33

Thoracic aortography, 33  
Abdominal aortography, 34  
Pulmonary arteriography, 36  
Selective abdominal visceral  
arteriography, 38  
Central venography, 43  
Selective visceral venography, 45  
Peripheral angiography, 46  
Angiography in the future, 49

### CEREBRAL ANGIOGRAPHY, 50

Cerebral anatomy, 50  
Cerebral angiographic studies, 53  
Aortic arch angiogram (for cranial  
vessels), 58  
Anterior circulation, 59  
Posterior circulation, 64



### INTERVENTIONAL RADIOLOGY, 68

Percutaneous transluminal  
angioplasty, 68  
Transcatheter embolization, 73  
Percutaneous nephrostomy tube  
placement and related  
procedures, 75  
Inferior vena cava filter  
placement, 78  
Transjugular intrahepatic  
portosystemic shunt, 81  
Other procedures, 81  
Interventional radiology, 82

### LYMPHOGRAPHY, 83

Definitions and indications, 83  
Procedures, 84

### PHOTOGRAPHIC SUBTRACTION TECHNIQUE, 86

Definitions and indications, 86  
First-order subtraction, 87  
Second-order subtraction, 88

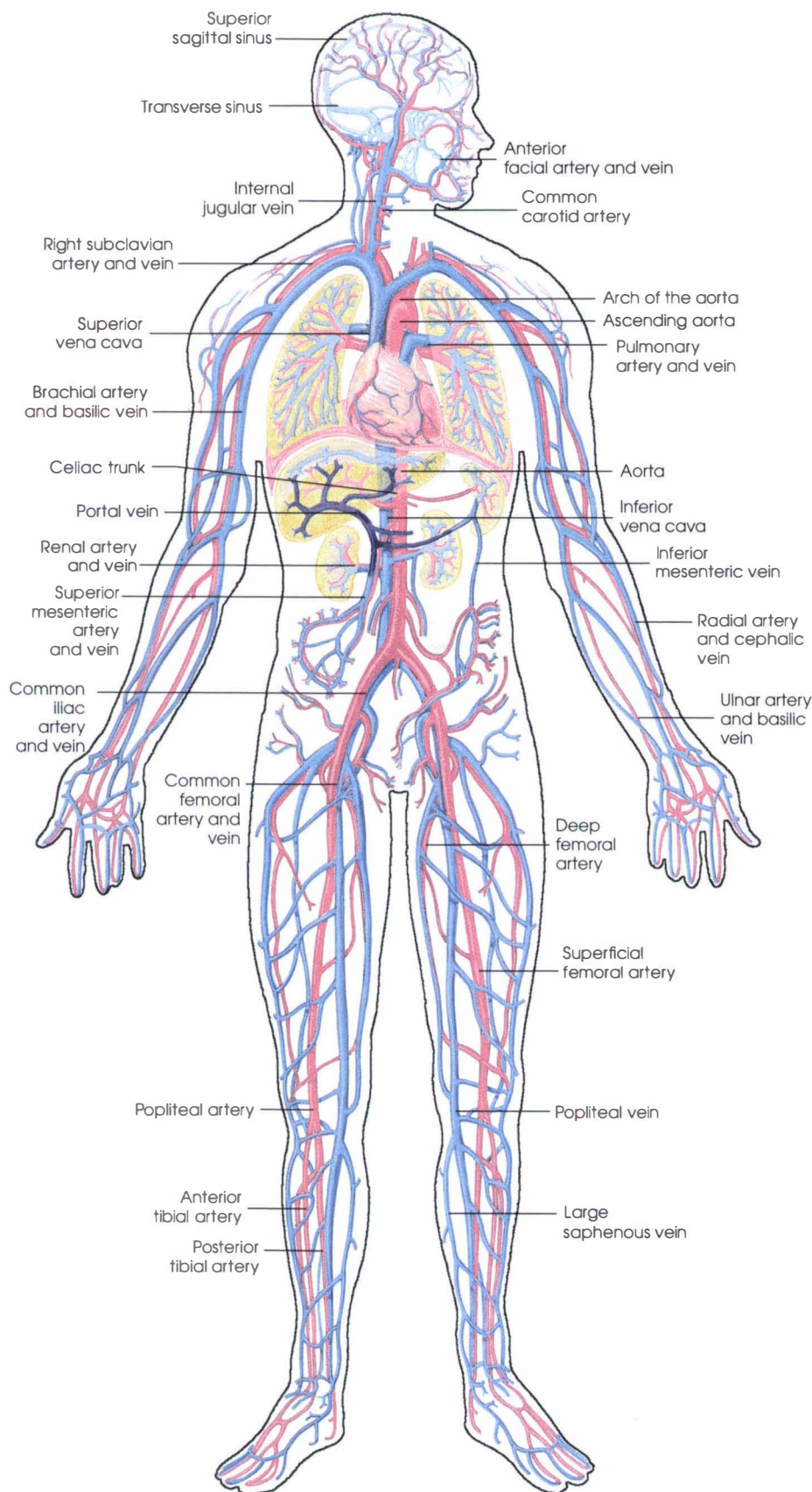
### CARDIAC CATHETERIZATION, 91

JEFFREY A. HUFF

KARL T. SUENISHI

Historical development, 91  
Principles of cardiac  
catheterization, 92  
Specialized equipment, 95  
Patient positioning for cardiac  
catheterization, 104  
Catheterization methods  
and techniques, 104  
Catheterization studies  
and procedures, 107  
Cardiac catheterization trends, 125  
Definition of terms, 126





## Circulatory System

The *circulatory system* has two complex systems of intimately associated vessels. Through these vessels, fluid is transported throughout the body in a continuous, unidirectional flow. The major portion of the circulatory system transports blood and is called the *blood-vascular system* (Fig. 26-1). The minor portion, called the *lymphatic system*, collects fluid from the tissue spaces. This fluid is filtered throughout the lymphatic system then conveys it back to the blood-vascular system. The fluid conveyed by the lymphatic system is called *lymph*.\* Together the blood-vascular and lymphatic systems carry oxygen and nutritive material to the tissues. They also collect and transport carbon dioxide and other waste products of metabolism from the tissues to the organs of excretion: the skin, lungs, liver, and kidneys.

\*Almost all italicized words on the succeeding pages are defined at the end of the chapter.

Fig. 26-1 Major arteries and veins: red, arterial; blue, venous; purple, portal.



## Blood-Vascular System

The blood-vascular system consists basically of the *heart*, *arteries*, *capillaries*, and *veins*. The *heart* serves as a pumping mechanism to keep the blood in constant circulation throughout the vast system of blood vessels. *Arteries* convey the blood *away* from the heart. *Veins* convey the blood *back* toward the heart. There are two circuits of blood vessels that branch out of the heart (Fig. 26-2).

The first circuit is the arterial circuit or the *systemic circulation*, which carries oxygenated blood to the organs and tissues. Every organ has its own vascular circuit that arises from the trunk artery and leads back to the trunk vein for return to the heart. The systemic arteries branch out, treelike, from the aorta to all parts of the body. The arteries are usually named according to their location. The systemic veins usually lie parallel to their respective arteries and are given the same names.

The second circuit is the *pulmonary circulation* which takes blood to the lungs for carbon dioxide exchange and for the re-oxygenation of the blood to which is then carried back to the arterial systemic circulation. The pulmonary trunk arises from the right ventricle of the heart, passes superiorly and posteriorly for a distance of about 2 inches (5 cm), and then divides into two branches, the right and left pulmonary arteries. These vessels enter the root of the respective lung and, following the course of the bronchi, divide and subdivide to form a dense network of capillaries surrounding the alveoli of the lungs. Through the thin walls of the capillaries, the blood discharges carbon dioxide and absorbs oxygen from the air contained in the alveoli. The oxygenated blood passes onward through the pulmonary veins for return to the heart. In the pulmonary circulation the deoxygenated blood is transported by the pulmonary arteries, and the oxygenated blood is transported by the pulmonary veins.

There are two main trunk vessels that arise from the heart. The first is the aorta for the systemic circulation—the arteries progressively diminish in size as they divide and subdivide along their course, finally ending in minute branches called *arterioles*. The arterioles divide to form the capillary vessels, and the branching process is then reversed: the *capillaries* unite to form *venules*, the beginning branches of the veins, which in turn unite and reunite to form larger and larger vessels as they approach the heart. These venous structures empty into the right atrium, then into the right ventricle and into the second main trunk that arises from the heart—the pulmonary trunk or the pulmonary circulation. The process of oxygen exchange in small venous struc-

tures is carried out, then on into larger and larger pulmonary veins. The pulmonary veins join to form 4 large veins (2 from each lung), which then empty into the left atrium, then into the left ventricle and then into the aorta, which starts the circulation again through out the body.

The pathway of venous drainage from the abdominal viscera to the liver is called the portal system. Unlike the systemic and pulmonary circuits, which begin and end at the heart, the portal system begins in the capillaries of the abdominal viscera and ends in the capillaries/sinusoids of the liver. The blood is filtered and after this process is completed, it exits the liver via the hepatic venous system, which then empties into the inferior vena cava just proximal to the right atrium.

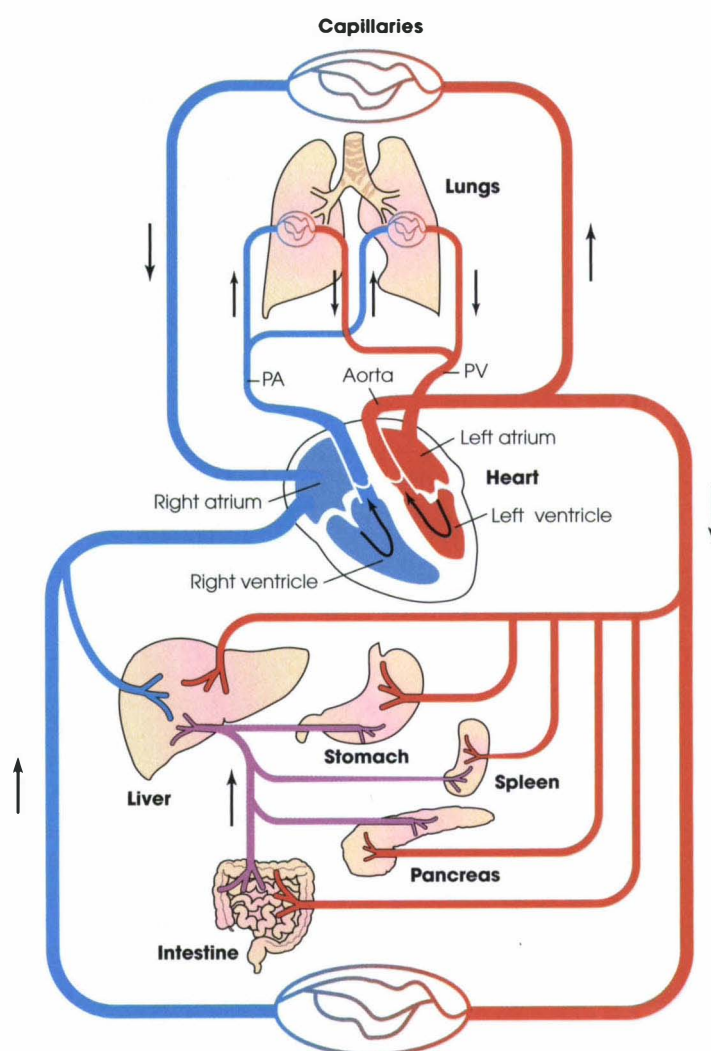


Fig. 26-2 Pulmonary, systemic, and portal circulation: oxygenated (red), deoxygenated (blue), and nutrient-rich (purple) blood.

The systemic veins are arranged in a superficial set and in a deep set with which the superficial veins communicate; both sets converge at a common trunk vein. The systemic veins end in two large vessels opening into the heart: the *superior vena cava* leads from the portion of the body above the diaphragm, and the *inferior vena cava* leads from below the level of the diaphragm.

The capillaries connect the arterioles and venules to form networks that pervade most organs and all other tissues supplied with blood. The capillary vessels have exceedingly thin walls through which the essential functions of the blood-vascular system take place—the blood constituents are filtered out and the waste products of cell activity are absorbed. The exchange takes place through the medium of tissue fluid, which is derived from the blood plasma and is drained off by the lymphatic system for return to the blood-vascular system. The tissue fluid undergoes modification in the lymphatic system. As soon as this tissue fluid enters the lymphatic capillaries, it is called *lymph*.

The *heart* is the central organ of the blood-vascular system and functions solely as a pump to keep the blood in circulation. It is shaped somewhat like a cone and measures approximately  $4\frac{3}{4}$  inches (12 cm) in length,  $3\frac{1}{2}$  inches (9 cm) in width, and  $2\frac{1}{2}$  inches (6 cm) in depth. The heart is situated obliquely in the middle mediastinum, largely to the left of the midsagittal plane. The base of the heart is directed superiorly, posteriorly, and to the right. The apex of the heart rests on the diaphragm and against the anterior chest wall and is directed anteriorly, inferiorly, and to the left.

The muscular wall of the heart is called the *myocardium*. Because of the force required to drive blood through the extensive systemic vessels, the myocardium is about three times as thick on the left side, (the arterial side), as on the right, (the venous side). The membrane that lines the interior of the heart is called the *endocardium*. The heart is enclosed in the double-walled *pericardial sac*. The exterior wall of this sac is fibrous. The thin, closely adherent membrane that covers the heart is referred to as the *epicardium* or, because it also serves as the serous inner wall of the pericardial sac, the *visceral pericardium*. The narrow, fluid-containing space between the two walls of the sac is called the *pericardial cavity*.

The heart is divided by a septa into right and left halves, with each half subdivided by a constriction into two cavities, or chambers. The two upper chambers are called *atria*, and each atrium consists of a principal cavity and of a lesser one called the *auricle*. The two lower chambers of the heart are called *ventricles*. The opening between the right atrium and right ventricle is controlled by the right atrioventricular (tricuspid) valve, and the opening between the left atrium and left ventricle is controlled by the left atrioventricular (mitral or bicuspid) valve.

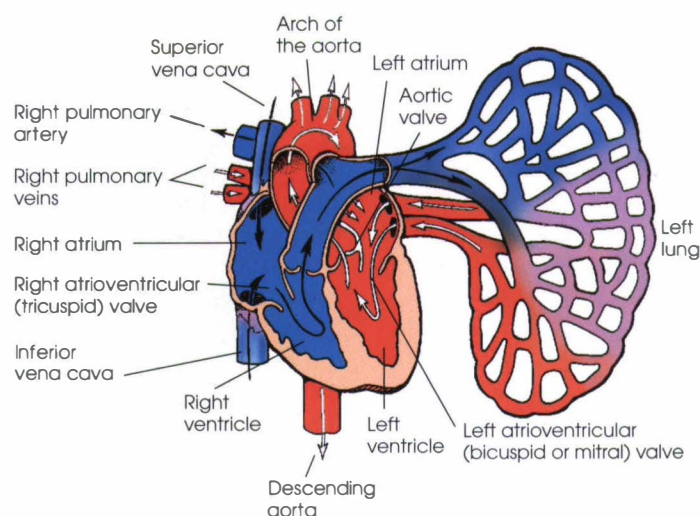
The atria and ventricles separately contract (systole) in pumping blood and relax or dilate (diastole) in receiving blood. The atria precede the ventricles in contraction; therefore, while the atria are in systole, the ventricles are in diastole. One phase of contraction (referred to as the heartbeat) and one phase of dilation are called the cardiac cycle. In the average adult, one cardiac cycle lasts 0.8 second. However, the heart rate, or number of pulsations per minute, varies with size, age, and gender. Heart rate is faster in small persons, young individuals, and females. The heart rate is also increased with exercise, food, and emotional disturbances.



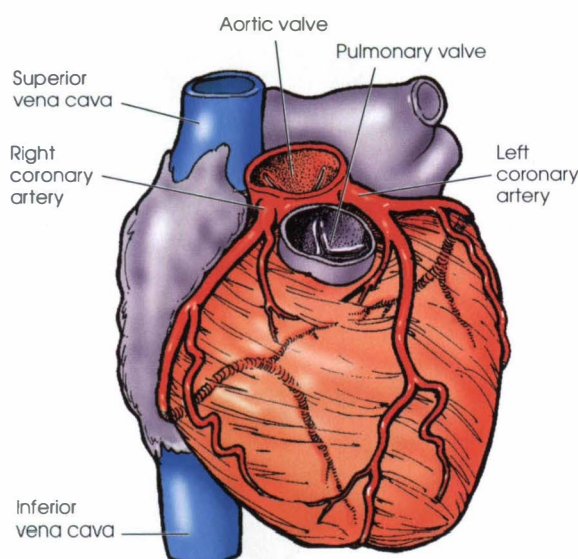
The atria function as receiving chambers, the superior and inferior venae cavae empty into the right atrium (Fig. 26-3). The two right and left pulmonary veins empty into the left atrium. The ventricles function as distributing chambers. The right side of the heart handles the venous, or deoxygenated blood, and the left side handles the arterial, or oxygenated blood. The left ventricle pumps oxygenated blood through the aortic valve into the aorta and the systemic circulation. The three major portions of the aorta are the ascending aorta, the aortic arch, and the descending aorta. The right ventricle pumps deoxygenated blood through the pulmonary valve into the pulmonary trunk and the pulmonary circulation.

Blood is supplied to the myocardium by the right and left coronary arteries. These vessels arise in the aortic sinus immediately superior to the aortic valve (Fig. 26-4). Most of the cardiac veins drain into the coronary sinus on the posterior aspect of the heart, and this sinus drains into the right atrium (Figs. 26-5).

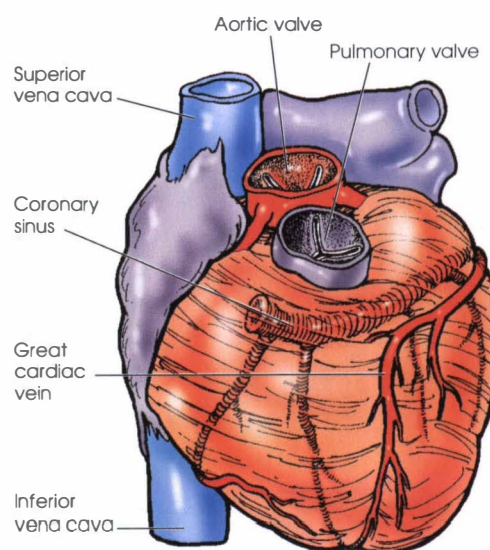
The ascending aorta arises from the superior portion of the left ventricle and passes superiorly and to the right for a short distance. It then arches posteriorly and to the left and descends along the left side of the vertebral column to the level of L4, where it divides into the right and left common iliac arteries. The common iliac arteries pass to the level of the lumbosacral junction, where each ends by dividing into the internal iliac, or hypogastric artery and the external iliac artery. The internal iliac artery passes into the pelvis. The external iliac artery passes to a point about midway between the anterior superior iliac spine (ASIS) and pubic symphysis and then enters the upper thigh to become the common femoral artery.



**Fig. 26-3** Heart and great vessels: deoxygenated blood flow (black arrows); oxygenated blood flow (white arrows).



**Fig. 26-4** Anterior view of coronary arteries.



**Fig. 26-5** Anterior view of coronary veins.

The velocity of blood circulation varies with the rate and intensity of the heart-beat. Velocity also varies in the different portions of the circulatory system based on distance from the heart. Therefore the speed of blood flow is highest in the large arteries arising at or near the heart because these vessels receive the full force of each wave of blood pumped out of the heart. The arterial walls expand with the pressure from each wave. The walls then rhythmically recoil, gradually diminishing the pressure of the advancing wave from point to point, until the flow of blood is normally reduced to a steady, nonpulsating stream through the capillaries and veins. The beat, or contraction and expansion of an artery, may be felt with the fingers at a number of points and is called the *pulse*.

Complete circulation of the blood through both the systemic and pulmonary circuits, from a given point and back again, requires about 23 seconds and an average of 27 heartbeats. In certain contrast examinations of the cardiovascular system, tests are conducted to determine the circulation time from the point of contrast medium injection to the site of interest.

## Lymphatic System

The lymphatic system consists of an elaborate arrangement of closed vessels that collect fluid from the tissue spaces and transport it to the blood-vascular system. Almost all lymphatic vessels are arranged in two sets: (1) a superficial set that lies immediately under the skin and accompanies the superficial veins and (2) a deep set that accompanies the deep blood vessels and with which the superficial lymphatics communicate (Fig. 26-6). The lymphatic system lacks a pumping mechanism such as the heart of the blood-vascular system. The lymphatic vessels are richly supplied with valves to prevent backflow, and the movement of the lymph through the system is believed to be maintained largely by extrinsic pressure from the surrounding organs and muscles.

The lymphatic system begins in complex networks of thin-walled, absorbent capillaries situated in the various organs and tissues. The capillaries unite to form larger vessels, which in turn form networks and unite to become still larger vessels as they approach the terminal collecting trunks. The terminal trunks communicate with the blood-vascular system.

The lymphatic vessels are small in caliber and have delicate, transparent walls. Along their course the collecting vessels pass through one or more nodular structures called *lymph nodes*. The nodes occur singly but are usually arranged in chains or groups of 2 to 20. The nodes are situated so that they form strategically placed centers toward which the conducting vessels converge. The nodes vary from the size of a pinhead to the size of an almond or larger. They may be spherical, oval, or kidney-shaped. Each node has a hilum through which the arteries enter and veins and efferent lymph vessels emerge; the afferent lymph vessels do not enter at the hilum. In addition to the lymphatic capillaries, blood vessels, and supporting structures, each lymph node contains masses, or follicles, of lymphocytes that are arranged around its circumference and from which cords of cells extend through the medullary portion of the node.

A number of conducting channels, here called *afferent lymph vessels*, enter the node opposite the hilum and break into wide capillaries that surround the lymph follicles and form a canal known as the *peripheral* or *marginal lymph sinus*. The network of capillaries continues into the medullary portion of the node, widens to form medullary sinuses, and then collects into several *efferent lymph vessels* that leave the node at the hilum. The conducting vessels may pass through several nodes along their course, each time undergoing the process of widening into sinuses. Lymphocytes, a variety of white blood cells formed in the lymph nodes, are added to the lymph while it is in the nodes. It is thought that a majority of the lymph is absorbed by the venous system from these nodes and only a small portion of the lymph is passed on through the conducting vessels.

The absorption and interchange of tissue fluids and cells take place through the thin walls of the capillaries. The lymph passes from the beginning capillaries through the conducting vessels, which eventually empty their contents into terminal lymph trunks for conveyance to the blood-vascular system. The main terminal trunk of the lymphatic system is called the *thoracic duct*. The lower, dilated portion of the duct is known as the *cisterna chyli*. The thoracic duct receives lymphatic drainage from all parts of the body below the diaphragm and from the left half of the body above the diaphragm. The thoracic duct extends from the level of L2 to the base of the neck, where it ends by opening into the venous system at the junction of the left subclavian and internal jugular veins.

Three terminal collecting trunks—the right jugular, the subclavian, and the bronchomediastinal trunks—receive the lymphatic drainage from the right half of the body above the diaphragm. These vessels open into the right subclavian vein separately or occasionally after uniting to form a common trunk called the right lymphatic duct.



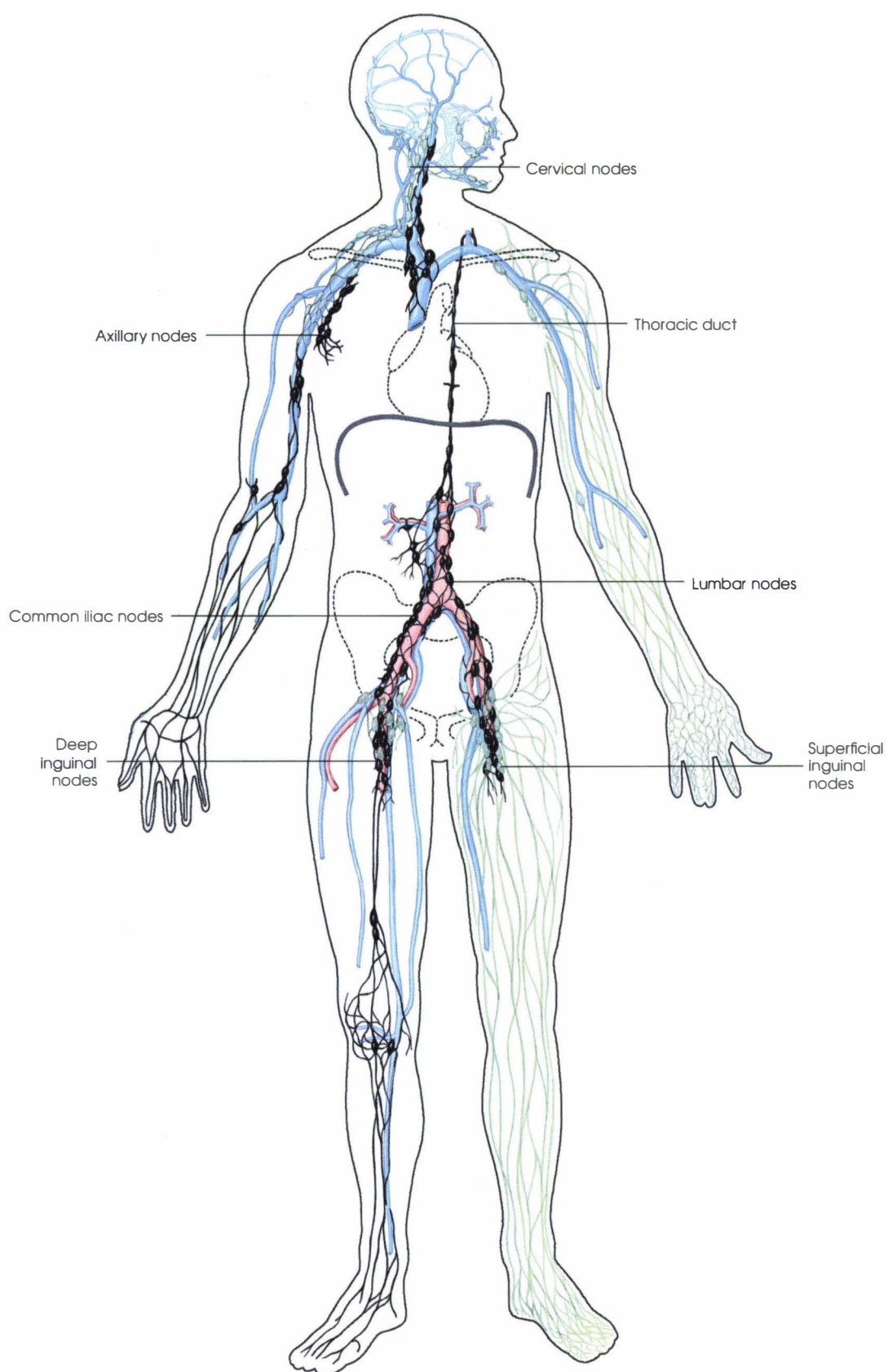


Fig. 26-6 Lymphatic system: *green*, superficial; *black*, deep.

## Definitions and Indications

Blood vessels are not normally visible in conventional radiography because no natural contrast exists between them and other soft tissues of the body. Therefore these vessels must be filled with a radiopaque contrast medium to delineate them for radiography. *Angiography* is a general term that describes the radiologic examination of vascular structures within the body after the introduction of an iodinated contrast medium or gas.

The visceral and peripheral angiography procedures identified in this chapter can be categorized generally as either *arteriography* or *venography*. Examinations are more precisely named for the specific blood vessel opacified and the method of injection.

Angiography is primarily used to identify the anatomy or pathologic process of blood vessels. Chronic cramping leg pain following physical exertion, a condition known as *claudication*, may prompt a physician to order an arteriogram of the lower limbs to determine if atherosclerosis is diminishing the blood supply to the leg muscles. A *stenosis* or *occlusion*, is commonly caused by *atherosclerosis*, and is an indication for an arteriogram. Cerebral angiography is performed to detect and verify the existence and exact position of an intracranial vascular lesion such as an *aneurysm*. Although most angiographic examinations are performed to investigate anatomic variances, some evaluate the motion of the part. Other vascular examinations evaluate suspected tumors by opacifying the organ of concern and once diagnosed, these lesions may be amenable to some type of intervention. Interventional Radiology now diagnoses lesions and then treats these lesions through an endovascular approach.

## Historical Development

In January 1896, just 10 weeks after the announcement of Roentgen's discovery, Haschek and Lindenthal announced that they had produced a radiograph demonstrating the blood vessels of an amputated hand using Teichman's mixture, a thick emulsion of chalk, as the contrast agent. This work heralded the beginning of angiography. The potential for this new type of examination to delineate vascular anatomy was immediately recognized. However, the advancement of angiography was hindered by the lack of suitable contrast media and low-risk techniques to deliver the media to the desired location. By the 1920s researchers were using sodium iodide as a contrast medium to produce lower limb studies comparable in quality to studies seen in modern angiography.

Yet limitations still existed. Until the 1950s, contrast medium was most commonly injected through a needle that punctured the vessel or through a ureteral catheter that passed into the body through a surgically exposed peripheral vessel. Then in 1952, shortly after the development of a flexible thin-walled catheter, Seldinger announced a *percutaneous* method of catheter introduction. The Seldinger technique eliminated the surgical risk, which exposed the vessel and tissues (see Fig. 26-8).

Early angiograms consisted of single radiographs or the visualization of vessels by fluoroscopy. Because the advantage of *serial imaging* was recognized, cassette changers, roll film changers, cut film changers, and cine and serial spot-filming/digital devices were developed. Pumps to inject contrast media were also developed to allow more rapid and precise control of injection rates and volumes than was possible by hand. Early mechanical injectors were powered by pressurized gas, and the injection rate was a function of the pressure setting. Electrically powered automatic injectors were subsequently developed that allowed the injection rate to be precisely set.



## Angiographic Studies

### CONTRAST MEDIA

Opaque contrast medium is used in angiographic studies, and use organic iodine solutions. Although usually tolerated, the injection of iodinated contrast medium may cause undesirable consequences. The contrast is subsequently filtered out of the bloodstream by the kidneys. It causes physiologic cardiovascular side effects, including peripheral vasodilation, blood pressure decrease, and cardiotoxicity. It may also produce nausea and an uncomfortable burning sensation in about 1 of 10 patients. Most significantly, the injection of iodinated contrast medium may invoke allergic reactions. These reactions may be minor (hives or slight difficulty in breathing) and not require any treatment, or they may be severe and require immediate medical intervention. Severe reactions are characterized by a state of shock in which the patient exhibits shallow breathing and a high pulse rate and may lose consciousness. Historically, 1 of every 14,000 patients suffers a severe allergic reaction. The administration of contrast medium is clearly one of the significant risks in angiography.

At the kilovolt (peak) (kVp) used in angiography, iodine is slightly more radiopaque, atom for atom, than lead. The iodine is incorporated into water-soluble molecules formed as triiodinated benzene rings. These molecules vary in exact composition. Some forms are organic salts that dissociate in solution and are therefore ionic. The iodinated anion is diatrizoate iothalamate or ioxaglate. The radiolucent cation is meglumine, sodium, or a combination of both. These ionic forms yield two particles in solution for every three iodine atoms (a 3:2 ratio) and are six to eight times as osmolar as plasma.

Other triiodinated benzene rings are created as nonionic molecules. These forms have three iodine atoms on each particle in solution (a 3:1 ratio) because they do not dissociate and are only two to three times as osmolar as plasma. Studies indicate that these properties of nonionic contrast media result in decreased nephrotoxicity to the kidneys. Nonionic contrast media also cause fewer physiologic cardiovascular side effects, less intense sensations, and fewer allergic reactions. They are, however, much more expensive than ionic media.

One form of ionic contrast medium is a dimer; two benzene rings are bonded together as the anion. This results in six iodine atoms for every two particles in solution, which yields the same 3:1 ratio as a nonionic contrast medium. The ionic dimer has advantages over the ionic monomeric molecule but lacks some of the properties of the nonionic molecule.

All forms of iodinated contrast media are available in a variety of iodine concentrations. The agents of higher concentration are more opaque. Typically, 30% iodine concentrations are used for cerebral and limb arteriography, whereas 35% concentrations are used for visceral angiography. Peripheral venography may be performed with 30% or lower concentrations. The ionic agents of higher concentration and the nonionic agents are more viscous and produce greater resistance in the catheter during injection.

### INJECTION TECHNIQUES

Selective injection through a catheter involves placing the catheter within a vessel so that the vessel and its major branches are opacified. In a selective injection, the catheter tip is positioned into the orifice of a specific artery so that only that specific vessel is injected. This has the advantage of more densely opacifying the vessel and limiting the superimposition of other vessels.

A contrast medium may be injected by hand with a syringe, but ideally should be injected by an automatic injector. The major advantage of automatic injectors is that a specific quantity of contrast medium can be injected during a predetermined period of time. Automatic injectors have controls to set the injection rate, injection volume, and maximum pressure. Another useful feature is a control to set a time interval during which the injector gradually achieves the set injection rate, which is the linear rise. This may prevent a catheter from being dislodged by whiplash.

Because the opacifying contrast medium is often carried away from the area of interest by blood flow, the injection and demonstration of opacified vessels usually occur simultaneously. Therefore the injector is often electronically connected to the rapid imaging equipment to coordinate the timing between the injector and the onset of imaging.

### EQUIPMENT

Most angiograms record flowing contrast medium in a series of images, which requires *rapid film changers*, cinefluorography devices, or digital subtraction angiography (DSA) (see Chapter 35). A number of rapid film changers are available from different manufacturers. All these devices move the film and permit exposures at intervals of a fraction of a second. One device is capable of changing as many as 12 films per second, although most film changers have a maximum speed of 6 films or fewer per second. These rapid film changers transport films from a supply magazine to a position between screens that come into close contact with the film during exposure and then retract so that the film can be transported into a receiving magazine. Cut-film changers that can move 20 or 30 35 × 35 cm (14 × 14 in) films are common.

Lower limb angiograms are the most likely to be performed using specialized cassette changers. These devices move large cassettes containing  $30 \times 120$  cm ( $11 \times 48$  in) or  $35 \times 130$  cm ( $14 \times 51$  in) film, depending on the manufacturer, into and out of the exposure field. Because these devices move heavy objects, they operate at slower maximum speeds, usually one cassette per second.

Fluoroscopy, cine, and DSA systems consist essentially of a camera that photographs the output phosphor of an image intensification system. Fluoroscopy and DSA employ a video camera. In DSA, the fluoroscopic image is digitized into serial images that are stored by a computer. The computer subtracts an early image, the mask image, (before contrast medium enters the vessel) from a later image (after the vessel opacifies) and displays the difference, or subtraction image, on the fluoroscopy monitor (see Chapter 35). Almost all image intensification devices used for vascular procedures include television monitoring. Such equipment allows angiographic examinations to be viewed on a television screen in real time and simultaneously recorded.

A cine camera uses 16- or 35-mm roll film and usually can achieve sequential exposure rates of up to 60 frames or more per second. The result is true motion picture radiography. The photographic resolution achieved with cine units is not as great as that seen with rapid film changers. However, many more events can be photographed with the cine attachment, and dynamic function can be more satisfactorily evaluated with cinefluorography.

Imaging systems may be used either singularly or in combination at right angles to obtain simultaneous frontal and lateral images of the vascular system under investigation with one injection of contrast medium. This arrangement of units is called a *biplane* imaging system.

Rapid serial radiographic imaging requires large focal-spot x-ray tubes capable of withstanding a high heat load. Magnification studies, however, require fractional focus tubes with focal spot sizes of between 0.1 and 0.3 mm. X-ray tubes may have to be specialized to satisfy these extreme demands. Rapid serial imaging also necessitates radiographic generators with high-power output. Because short exposure times are needed to compensate for all patient motion, the generators must be capable of producing high-milliampere output. The combination of high kilowatt-rated generators and rare earth film-screen technology significantly aids in decreasing the radiation dose to the patient while producing radiographs of improved quality, with the added advantage of prolonging the life of the high-powered generators and x-ray tubes.

A comprehensive angiographic room contains a great amount of equipment other than radiologic devices. Monitoring systems record patient electrocardiographic data and blood pressure readings, as well as pulse oximetry. Emergency equipment may include resuscitation equipment such as a defibrillator for the heart, and anesthesia apparatus. The cardiovascular and interventional technologist (CIT) must be familiar with the use of each piece of equipment (Fig. 26-7).

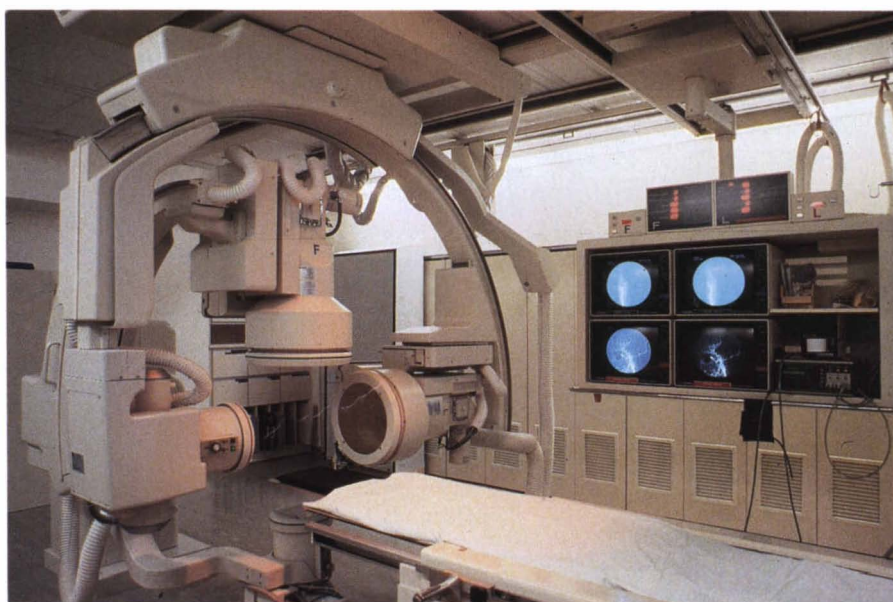


Fig. 26-7 Modern biplane digital angiographic suite.



## MAGNIFICATION

Magnification occurs both intentionally and unintentionally in angiographic imaging sequences. Intentional use of magnification can result in a significant increase in resolution of fine vessel recorded detail. Fractional focal spot tubes of 0.3 mm or less are necessary for direct radiographic magnification techniques. The selection of a fractional focal spot necessitates the use of low milliamperage. Short exposure time is maintained by the use of the air gap rather than the grid to control scatter radiation.

The formula for magnification is:

$$M = \frac{SID}{SOD} \text{ or } \frac{SID}{SID - OID}$$

The SID is the *source-to-image receptor distance*, the SOD is the *source-to-object distance*, and the OID is the *object-to-image receptor distance*. For a 2:1 magnification study using a SID of 40 inches (101 cm) both the focal spot and the image receptor are positioned 20 inches (50 cm) from the area of interest. A 3:1 magnification study using a 40-inch (101-cm) SID is accomplished by placing the focal spot 13 inches (33 cm) from the area of interest and the image receptor 27 inches (68 cm) from the area of interest.

Unintentional magnification occurs when the area of interest cannot be placed in direct contact with the image receptor. This is particularly a problem in the biplane imaging sequence, in which the need to center the area of interest in the first plane may create some unavoidable distance of the body part to the image receptor in the second plane. Even in single plane imaging, vascular structures are separated from the image receptor by some distance. The magnification that occurs as a result of these circumstances is frequently 20% to 25%. For example, a 25% magnification occurs when a vessel within the body is 8 inches (20 cm) from the image receptor—an OID of 8 inches (20 cm)—and the SID is 40 inches (101 cm).

Angiographic images therefore do not represent vessels at their actual size. This must be taken into account when direct measurements are made from angiographic images. Increasing the SID while maintaining the OID can reduce unintentional magnification. Increasing the SID may not be an option, however, if the increase in technical factors would exceed tube output capacity or exposure time maximum.

## FILM AND DIGITAL SUBTRACTION ANGIOGRAPHIC PROGRAMMING

Film programming is the task of controlling the rate and number of serial exposures made with a film changer. Programming is accomplished either through manipulation of the device intimately associated to the film changer, known as the *film programmer*, or through a combination of precisely patterning films in the film changer's supply magazine and setting the film programmer to operate the film changer at specific rates for specific amounts of time. Film programmers instruct the film changers to cycle at a specific rate, but every cycle does not necessarily transport and expose a film.

When two film changers operate together for simultaneous *biplane* imaging, exposures in both planes cannot be made at the same moment, because scatter radiation would fog the films. Yet, biplane changers must cycle exactly together so that synchronization can be electronically controlled. Therefore it is necessary to alternate the cycles that transport film in the two planes. In the first cycle, even though both changers are cycling, only one changer is allowed to transport and expose a film. In the second cycle, the changer that transported film in the first cycle is allowed to cycle empty while the other changer transports and exposes a film. This process of changers alternating between transporting and not transporting film during opposite cycles must continue throughout the series. The maximum exposure rate of a film changer operated in the biplane mode is one half of its maximum cycle rate because only every other cycle transports and exposes a film.

The most sophisticated film programmers and all DSA systems (see Chapter 35) automatically control the alternation of images in the biplane mode. The CIT selects single-plane or biplane mode and enters the number of exposures to be made in each second interval of the series. With less sophisticated film programming systems the CIT has control of the cycle rate and rate duration but must manually select the cycles that will transport film. For a biplane program with manually loaded equipment, the film supply magazine for the AP changer is loaded with film in the odd-numbered spaces. The even-numbered spaces are left empty. The lateral film supply magazine is loaded in the even-numbered spaces. The film programmer must then be set to cycle the changers at a rate double to the film rate for each plane. The rate duration, however, remains the same. The time interval in which the film remains motionless for exposure must be known for every cycle rate so that a cycle rate with a motionless interval greater than the radiographic exposure time can be selected.

## CATHETERIZATION

Catheterization for filling vessels with contrast media is a technique that is preferred over needle injection of the media. The advantages of catheterization are as follows:

1. The risk of *extravasation* is reduced.
2. Most body parts can be reached for selective injection.
3. The patient can be positioned as needed.
4. The catheter can be safely left in the body while radiographs are being examined.

The femoral, axillary, and brachial arteries are the most commonly punctured vessels. The transfemoral site is preferred because it is associated with the fewest risks.

The most widely used catheterization method is the Seldinger technique.<sup>1</sup> Seldinger described the method as puncture of both walls of the vessel, (the anterior and posterior walls). However, the modified Seldinger technique allows for puncture of the anterior wall only. The steps of the technique are described in

(Fig. 26-8). The procedure is performed under sterile conditions. The catheterization site is suitably cleaned and then surgically draped. The patient is given local anesthesia at the catheterization site. With this percutaneous technique the arteriotomy or venotomy is no larger than the catheter itself. Therefore hemorrhage is minimized. Patients can usually resume normal activity within 24 hours after the examination. In some diagnostic angiograms, the procedure can be performed in the early morning and the patient may be discharged later that same day. The risk of infection is lower than in surgical procedures because the vessel and tissues are not exposed.

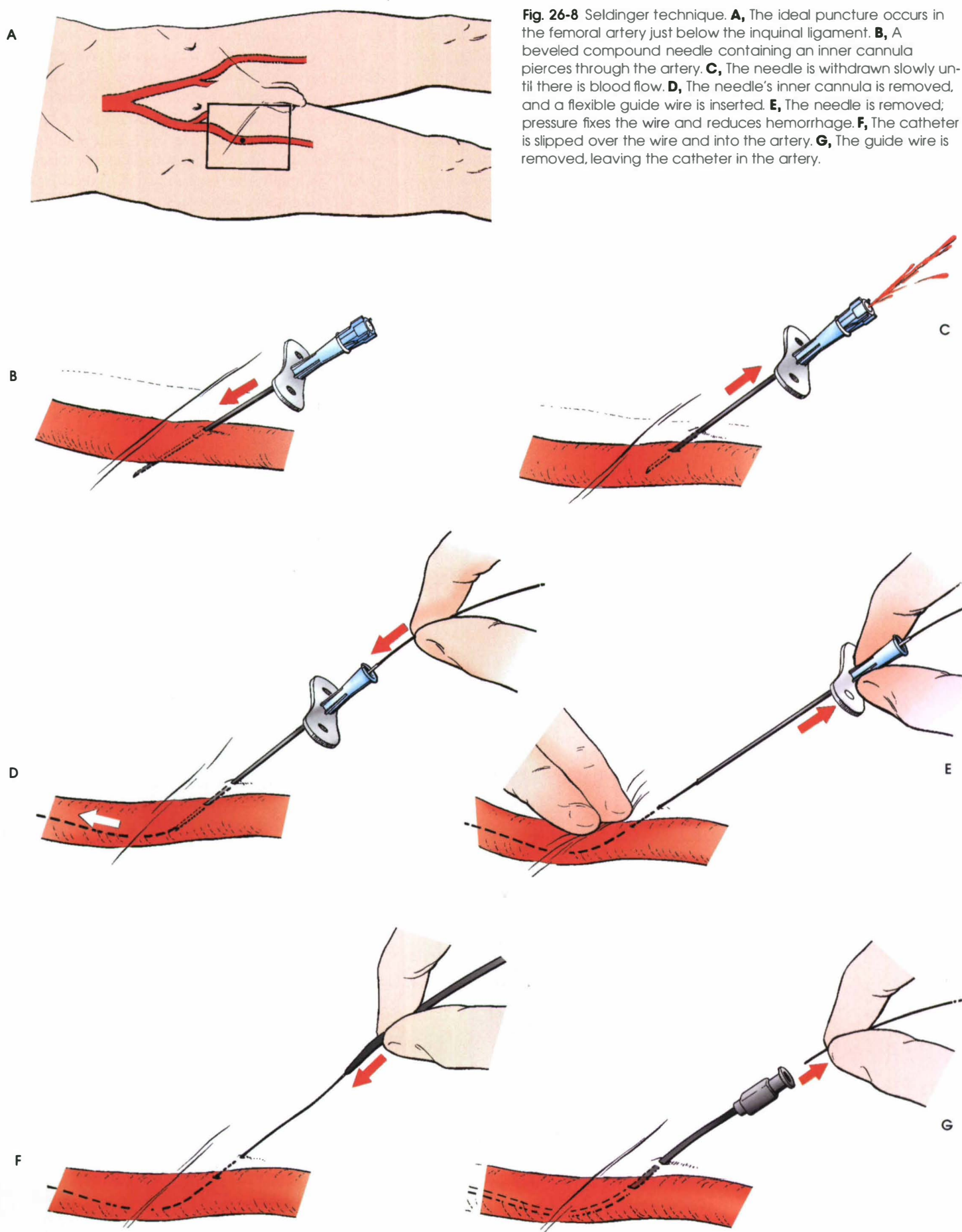
After a catheter is introduced into the blood-vascular system, it can be maneuvered by pushing, pulling, and turning the part of the catheter still outside the patient so that the part of the catheter inside the patient travels to a specific location. A wire is sometimes positioned inside the catheter to help manipulate and guide the catheter to the desired location. When the wire is removed from the catheter, the catheter is infused with sterile solution, most commonly, heparinized saline, to help prevent clot formation. Infusing the catheter and assisting the physician in the catheterization process may be the CIT responsibility.

When the examination is complete, the catheter is removed. Pressure is applied to the site until complete hemostasis is achieved, but blood flow through the vessel is maintained. The patient is placed on complete bed rest and observed for the development of bleeding or *hematoma*. Newer closure devices, which close the vessel percutaneously, can also be utilized to close the puncture site.

When peripheral artery sites are unavailable, a catheter may sometimes be introduced into the aorta using the translumbar aortic approach. For this technique the patient is positioned prone, and a special catheter introducer system is inserted percutaneously through the posterolateral aspect of the back and directed superiorly so that the catheter enters the aorta around the T11-T12 level.

<sup>1</sup>Seldinger SF: Percutaneous selective angiography of the aorta: preliminary report. *Acta Radiol* (Stockh) 45:15, 1956.





Catheters are produced in various forms, each with a particular advantage in shape, maneuverability or torque, and maximum injection rate (Fig. 26-9). Angiographic catheters are made of pliable plastic that allows them to straighten for insertion over the guide wire, also called a *wire guide*. They normally resume their original shape after the guide wire is withdrawn. However, it usually requires manipulation from the angiographer to resume its original shape. Catheters with a bent tip are designed for maneuverability into artery origins for selective injections. They may have only an end hole, or they may have multiple side holes. Some catheters have multiple side holes to facilitate high injection rates but are used only in large vascular structures for flush injections. A "pigtail" catheter is a special multiple side hole catheter that allows higher volumes of contrast to be injected with less whiplash effect, thus causing less damage to the vessel being injected.

Common angiographic catheters range in size from 4 Fr (0.05 in) to 7 Fr (0.09 in), although even smaller or larger sizes may be used. Most have inner lumens that allow them to be inserted over guide wires ranging from 0.032 to 0.038 inches in diameter.

## PATIENT CARE

Before the initiation of an angiographic procedure, it is appropriate to explain the process and the potential complications to the patient. Written consent is often obtained after an explanation. Potential complications include a vasovagal reaction; stroke; bleeding at the puncture site; nerve, blood vessel, or tissue damage; and an allergic reaction to the contrast medium. Bleeding at the puncture site is usually easily controlled with pressure to the site. Blood vessel and tissue damage may require a surgical procedure. A vasovagal reaction is characterized by sweating and nausea caused by a drop in blood pressure. The patient's legs should be elevated, and IV fluids may be administered to help restore blood pressure. Minor allergic reactions to iodinated contrast media, such as hives and congestion, are usually controlled with medications and may not require treatment. Severe allergic reactions may result in shock, which is characterized by shallow breathing, high pulse rate, and possibly loss of consciousness. Of course, angiography is performed only if the benefits of the examination outweigh the risks.

Patients are usually restricted to clear liquid intake and routine medications before undergoing angiography. Adequate hydration from liquid intake may minimize kidney damage caused by iodinated contrast media. Solid food intake is restricted to reduce the risk of aspiration related to nausea. Contraindications to angiography are determined by physicians and include previous severe allergic reaction to iodinated contrast media, severely impaired renal function, impaired blood clotting factors, and inability to undergo a surgical procedure or general anesthesia.

Because the risks of general anesthesia are greater than those associated with most angiographic procedures, conscious sedation maybe used for the procedure. Thoughtful communication from the CIT and physician also calms and reassures the patient. The CIT or physician should warn the patient about the sensations caused by the contrast medium and the noise produced by the imaging equipment. This information also reduces the patient's anxiety and helps ensure a good radiographic series with no patient motion.

## ANGIOGRAPHIC TEAM

The angiographic team consists of the physician (usually an interventional radiologist), the CIT, and other specialists, such as an anesthetist and a nurse.

The CIT often assists in performing procedures that require sterile technique and may be responsible for operating monitoring devices and emergency equipment, as well as the radiographic equipment. When required to operate the supporting apparatus, the CIT must receive adequate training for proper use of the equipment. Instruction in patient care techniques and sterile procedure is included in the basic preparation of the CIT.

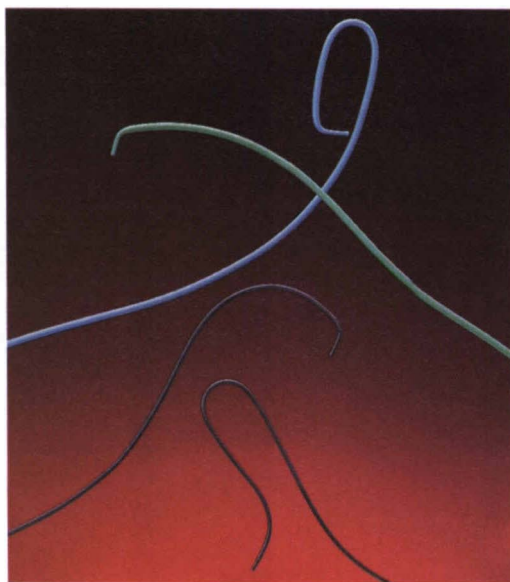


Fig. 26-9 Selected catheter shapes used for angiography.

(Courtesy Cook, Inc., Bloomington, Ind.)



The most satisfactory visualization of the aorta is achieved by placing a multihole catheter into the aorta at the desired level, utilizing the Seldinger technique. *Aortography* is usually performed with the patient in the supine position for simultaneous frontal and lateral imaging with the central ray perpendicular to the imaging system. For translumbar aortic catheter introduction, the patient must be in the prone position.

## Thoracic Aortography

Thoracic aortography may be performed to rule out an aortic aneurysm or to evaluate congenital or post surgical conditions. The examination is also used in patients with *aortic dissection*. Biplane imaging is recommended so that AP or PA and lateral projections can be obtained with one contrast medium injection. The CIT observes the following guidelines:

- For lateral projections, move the patient's arms superiorly so that they do not appear in the image.
- For best results, increase the lateral SID, usually to 60 inches (152 cm), so that magnification is reduced.
- If biplane equipment is not available, use a single-plane 45-degree right posterior oblique (RPO) or left anterior oblique (LAO) body position, which often produces an adequate study of the aorta.
- For all projections, direct the perpendicular central ray to the center of the chest at the level of T7. This should allow visualization of the entire thoracic aorta, including the proximal brachiocephalic, carotid, and subclavian vessels.

The contrast medium is injected at rates ranging from 25 to 35 ml/sec for a total volume of 50 to 70 ml. The CIT then performs the following steps:

- Begin imaging simultaneously with injection of the contrast material.
- Make exposures in each plane at rates ranging from one and one-half to three exposures per second for 3 to 4 seconds; exposures may then slow to one image or less per second for an additional 3 to 5 seconds.
- Make the exposures at the end of suspended inspiration (Figs. 26-10 and 26-11).

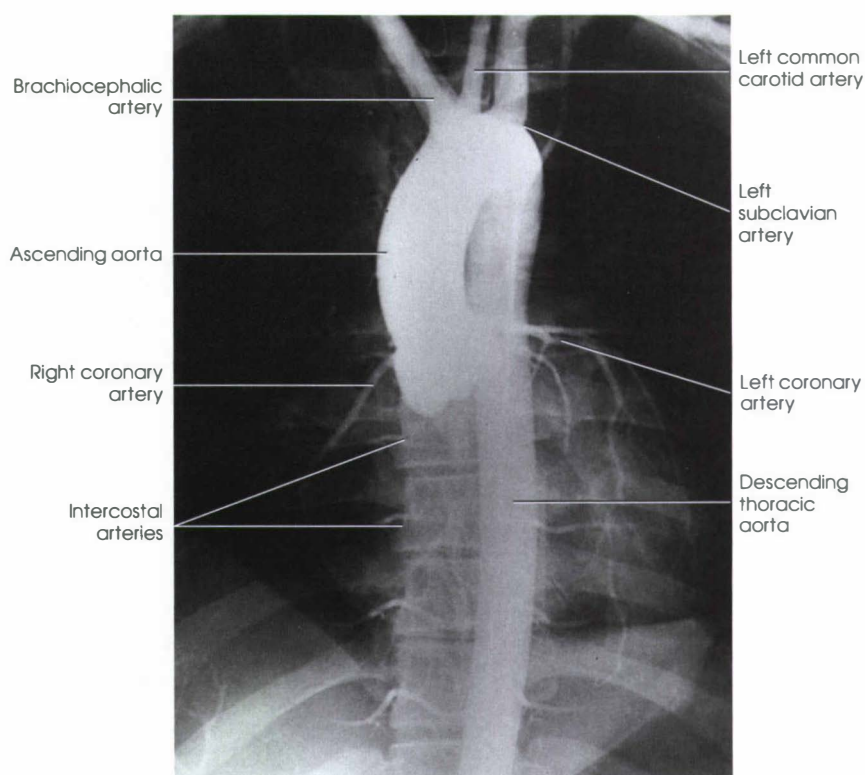


Fig. 26-10 AP thoracic aorta that also demonstrates right and left coronary arteries.

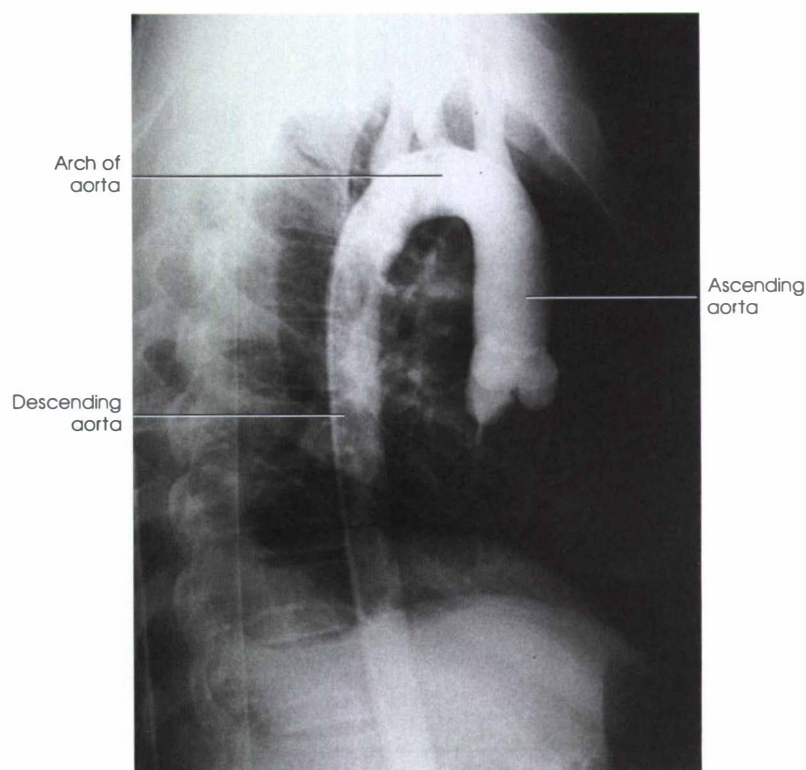


Fig. 26-11 Lateral thoracic aorta.

## Abdominal Aortography

Abdominal aortography may be performed to evaluate abdominal aortic aneurysm, occlusion, or atherosclerotic disease. Simultaneous AP and lateral projections are recommended. The CIT observes the following guidelines:

- For the lateral projection, move the patient's arms superiorly so that they are out of the image field.
- Usually, collimate the field in the AP aspect of the lateral projection.
- Direct the perpendicular central ray at the level of L2 so that the aorta is visualized from the diaphragm to the aortic bifurcation. The AP projection best demonstrates the renal artery origins, the aortic bifurcation, and the course and general condition of all abdominal visceral branches. The lateral projection best demonstrates the origins of the celiac and superior mesenteric arteries because these vessels arise from the anterior abdominal aorta.
- Make the exposures. Representative injection and imaging programs are 25 ml/sec for a 60-ml total volume of contrast medium and two images per second for 4 seconds followed by one image per second for 4 seconds in each plane.
- Begin making the exposures simultaneously with the beginning of the injection and the end of suspended expiration (Figs. 26-12 and 26-13).



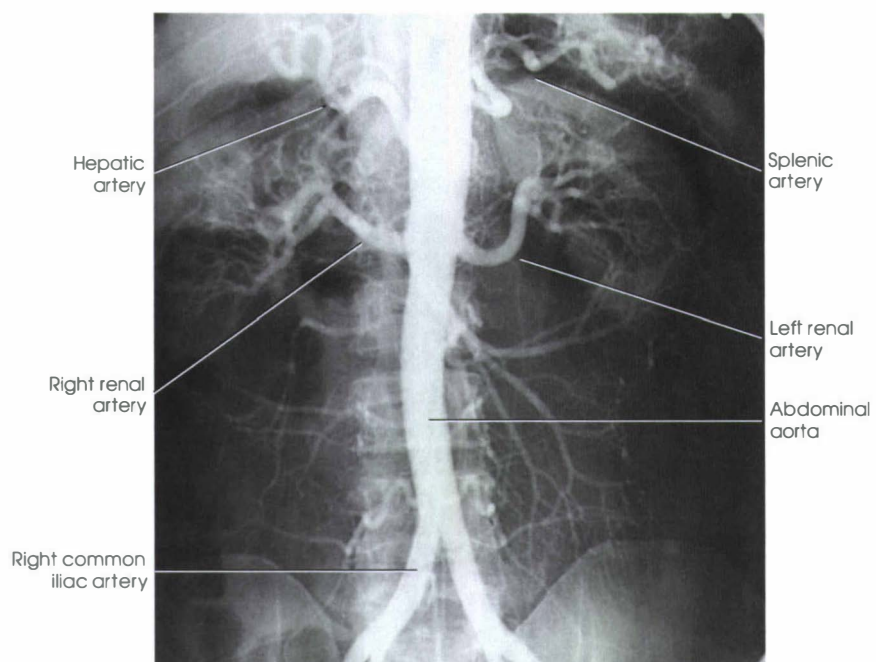


Fig. 26-12 AP abdominal aorta.

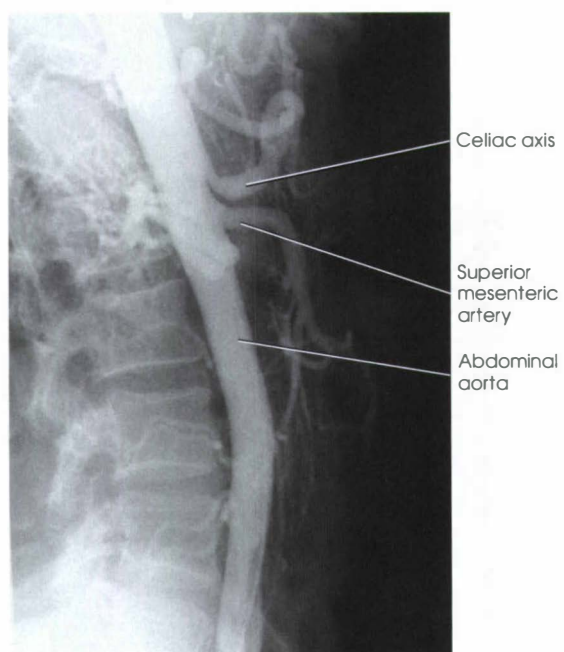


Fig. 26-13 Lateral abdominal aorta.

## Pulmonary Arteriography

Under fluoroscopic control, a catheter is passed from a peripheral vein through the vena cava and right side of the heart and into the pulmonary arteries. This technique is usually employed for a selective injection, and the examination is primarily performed for the evaluation of pulmonary embolic disease.

Simultaneous AP and oblique projections (Figs. 26-14 and 26-15) of the supine patient are recommended for this procedure. The suggested SID for the lateral projection is 60 inches (152 cm). The CIT observes the following guidelines:

- Move the patient's arms superiorly so that they are out of the field of view.
- When biplane projections are not possible, use a single-plane 25- to 35-degree RAO and LAO or LPO and RPO position.
- Direct the central ray perpendicular to the image receptor for all exposures.
- A compensating (trough) filter can be utilized to obtain a radiograph with more uniform density between the vertebrae and the lungs if needed.
- In studies of the pulmonary arteries, lengthen the time of the imaging program to reveal the opacified left atrium, left ventricle, and thoracic aorta (Figs. 26-16 and 26-17).
- Make the exposures. Representative injection and imaging programs are 25 ml/sec for a 50-ml total volume of contrast medium and two to four images per second for 4 seconds followed by one per second for an additional 4 seconds in each plane (Figs. 26-17 to 26-20).

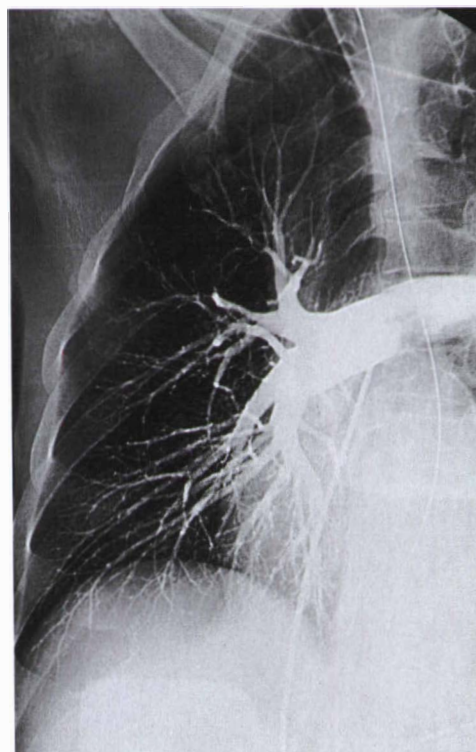


Fig. 26-14 Right pulmonary artery during early phase of injection.

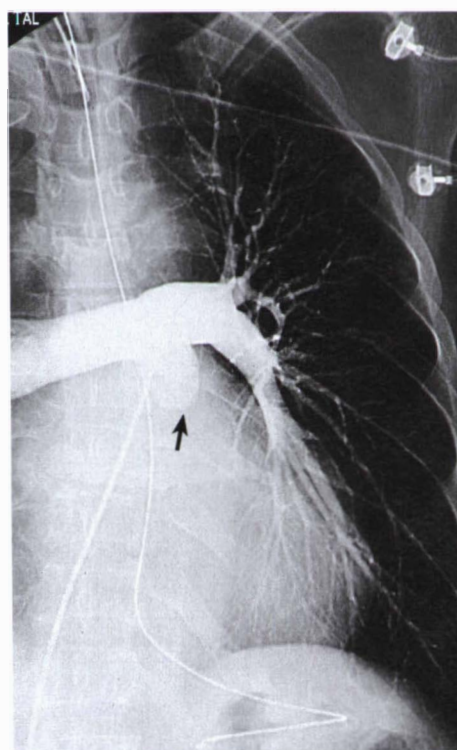
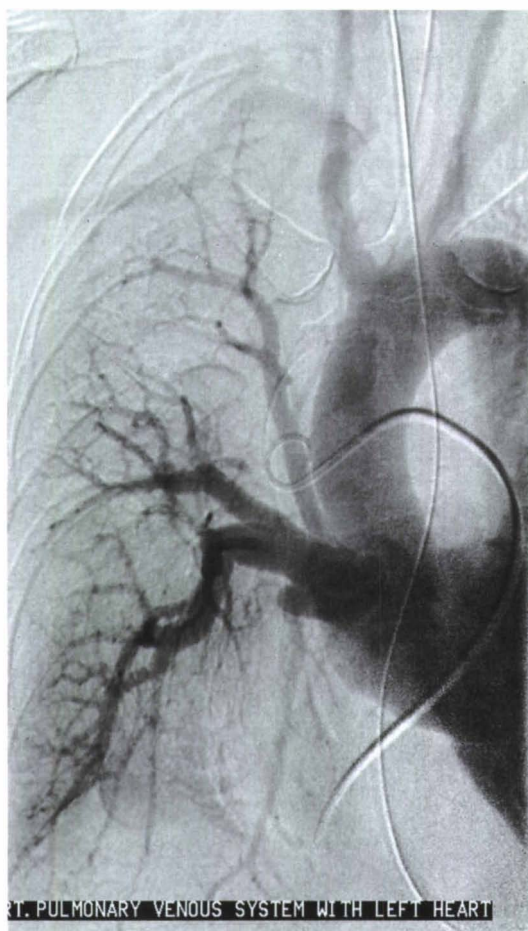
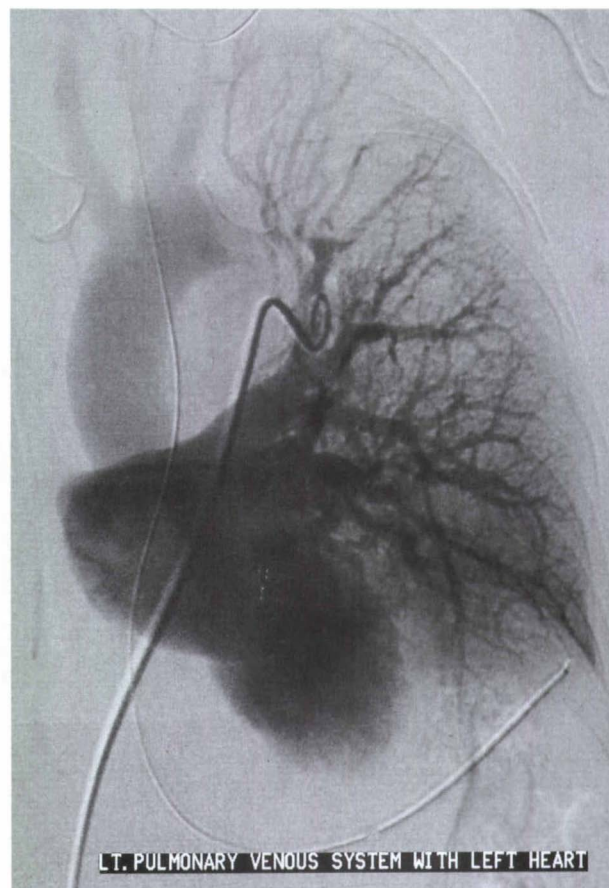


Fig. 26-15 Left pulmonary artery during early phase of injection, note is made of the pulmonary outflow tract (arrow).





**Fig. 26-16** Late-phase right pulmonary artery injection demonstrating left atrium, left ventricle, and thoracic aorta.



**Fig. 26-17** Late-phase left pulmonary artery injection demonstrating left atrium, left ventricle, and thoracic aorta.

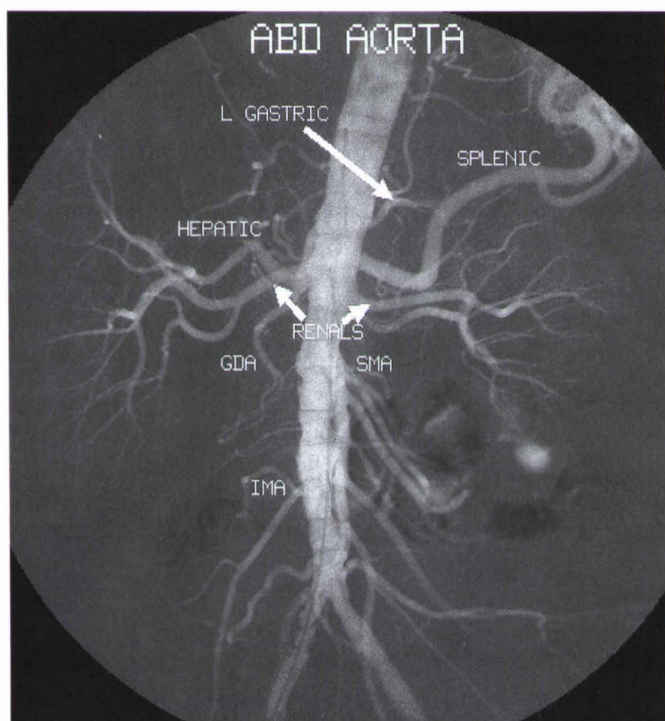


Fig. 26-18 Abdominal aortogram demonstrating the visceral arteries.

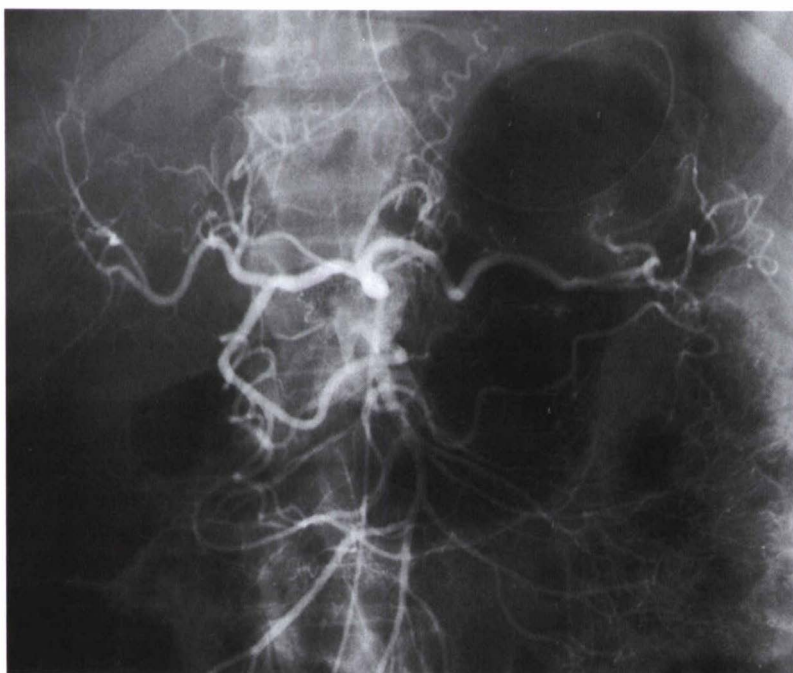


Fig. 26-19 Superselctive celiac artery injection.

## Selective Abdominal Visceral Arteriography

Abdominal visceral arteriographic studies (Fig. 26-18) are usually performed to visualize tumor vascularity or to rule out atherosclerotic disease, thrombosis, occlusion, and bleeding. An appropriately shaped catheter is introduced, usually from a transfemoral artery puncture, and advanced into the orifice of the desired artery. The CIT observes the following steps:

- Perform all selective studies initially with the patient in the supine position for single-plane frontal images.
- Direct the central ray perpendicular to the image receptor.
- In most patients, obtain a preliminary radiograph to establish optimum exposure and positioning and to check for retained contrast material.
- If necessary, use oblique projections to improve visualization or avoid superimposition of vessels.
- For all abdominal visceral studies, obtain radiographs during suspended expiration.
- Selective abdominal visceral arteriograms are described in the following sections.

### CELIAC ARTERIOGRAM

The celiac artery normally arises from the aorta at the level of T12 and carries blood to the stomach and the proximal duodenum, liver, spleen, and pancreas. These steps are followed:

- For the angiographic examination, center the patient to the image receptor.
- Direct the central ray to L1 (Fig. 26-19).
- Make the exposures. Representative injection and image programs are 10 ml/sec for a 40-ml total volume of contrast medium and two images per second for 5 seconds followed by one per second for 5 seconds.



## HEPATIC ARTERIOGRAM

The common hepatic artery branches from the right side of the celiac artery and supplies circulation to the liver, stomach, and the proximal duodenum, and pancreas. The CIT follows these steps:

- Position the patient so that the upper and right margins of the liver are at the respective margins of the image receptor (Fig. 26-20).
- Make the exposures. Representative injection and imaging programs are 8 ml/sec for a 40-ml total volume of contrast medium and two images per second for 5 seconds followed by one per second for 5 seconds.

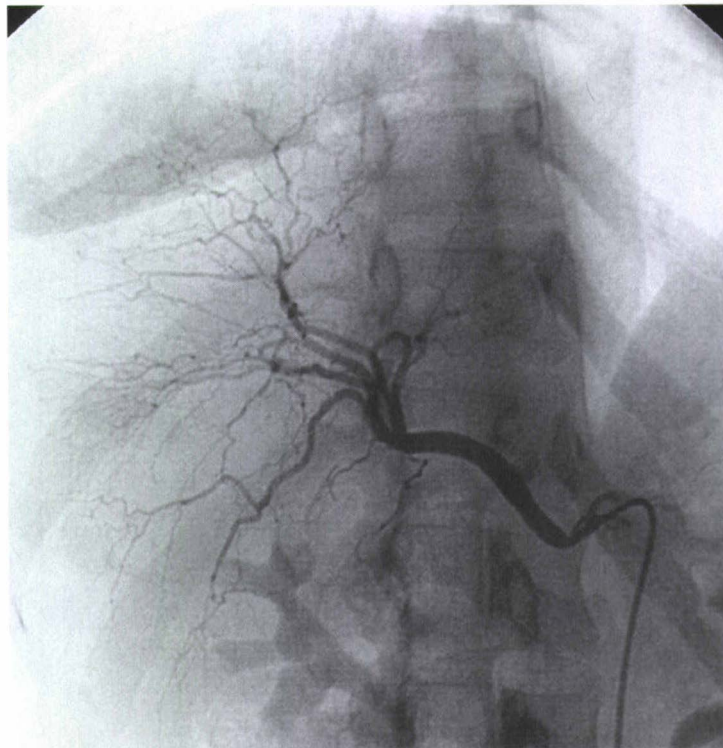
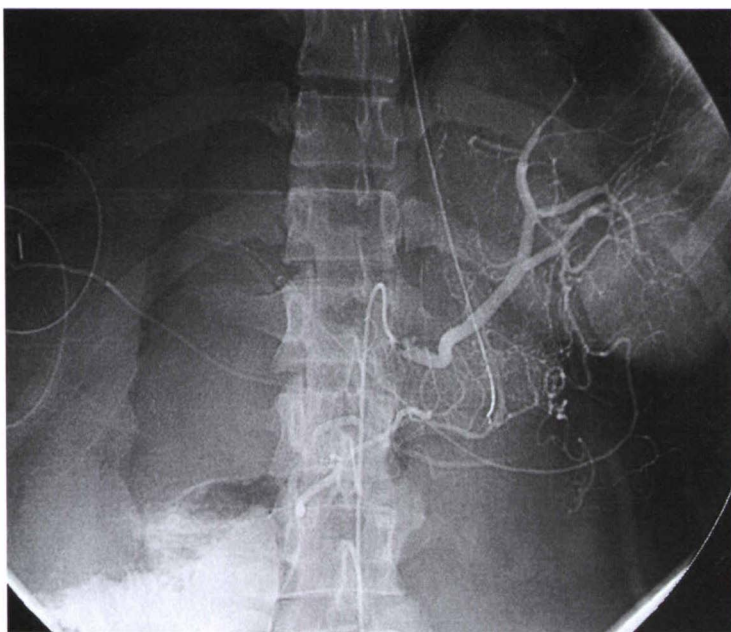


Fig. 26-20 Superselective hepatic artery injection.



**Fig. 26-21** Superselective splenic artery injection.

### **SPLenic ARTERIOGRAM**

The splenic artery branches from the left side of the celiac artery and supplies blood to the spleen and pancreas. The steps are as follows:

- Position the patient to place the left and upper margins of the spleen at the respective margins of the image receptor (Fig. 26-21).
- Splenic artery injection can demonstrate the portal venous system on the late venous images.
- For demonstration of the portal vein, center the patient to the image receptor.
- Make the exposures. Representative injection and imaging programs for a standard splenic arteriogram are 8 ml/sec for a 40-ml total volume of contrast medium and two images per second for 5 seconds followed by one per second for 5 seconds. Representative programs for portal vein visualization are 8 ml/sec for a 40-ml total volume and one image per second for 20 seconds.



### SUPERIOR MESENTERIC ARTERIOGRAM

The superior mesenteric artery (SMA) supplies blood to the small intestine and the ascending and transverse colon. It arises at about the level of L1 and descends to L5-S1. The CIT follows these steps:

- To demonstrate the SMA, center the patient to the midline of the image receptor.
- Direct the central ray to the level of L3 (Fig. 26-22).
- Make the exposures. Representative injection and imaging programs are 8 ml/sec for a 50-ml total volume of contrast medium and two images per second for 5 seconds followed by one per second for 5 seconds.
- When attempting to visualize bleeding sites, conduct the imaging at one image per second for 18 seconds.
- Use an increased injection volume and an extended imaging sequence to optimize visualization of the mesenteric and portal veins.

### INFERIOR MESENTERIC ARTERIOGRAM

The inferior mesenteric artery (IMA) supplies blood to the splenic flexure, descending colon, and rectosigmoid area. It arises from the left side of the aorta at about the level of L3 and descends into the pelvis. The steps are as follows:

- To best visualize the IMA, use a 15-degree right anterior oblique (RAO) or left posterior oblique (LPO) position that places the descending colon and rectum at the left and inferior margins of the image (Fig. 26-23).
- Make the exposures. A representative injection program is 3 ml/sec for a 15-ml total volume of contrast medium. The imaging is the same as that for the SMA.

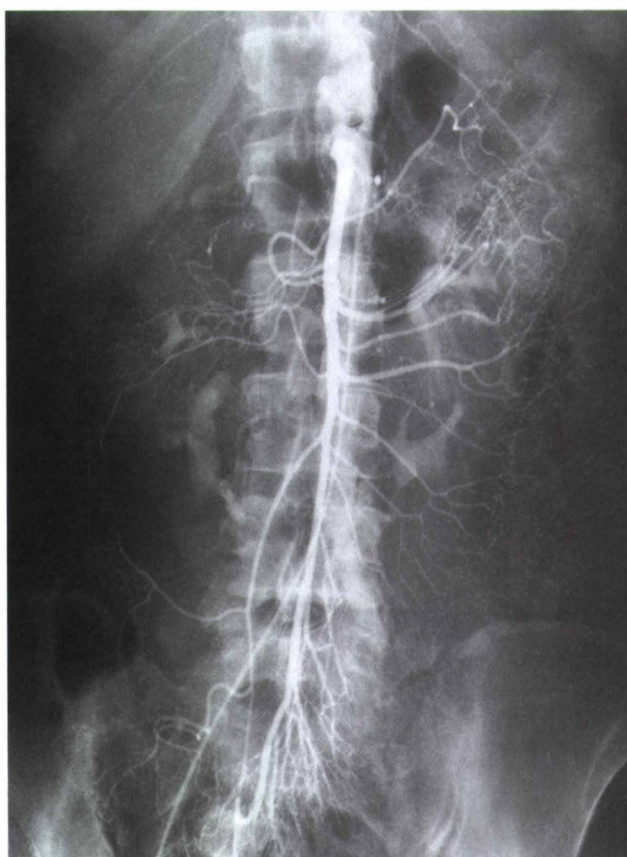


Fig. 26-22 Selective superior mesenteric artery injection.



Fig. 26-23 Selective inferior mesenteric artery injection.

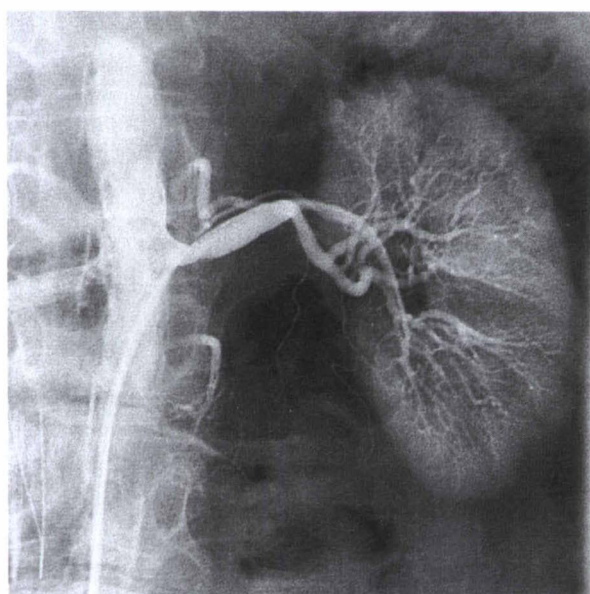


Fig. 26-24 Selective left renal artery injection in early arterial phase.

### RENAL ARTERIOGRAM

The renal arteries arise from the right and left side of the aorta between L1 and L2 and supply blood to the respective kidney. The following steps are observed:

- Before performing this selective study, check the patient's IV urogram or renal flush arteriogram for the exact size and location of the kidneys. This step enables precise collimation to the kidney being studied and ensures exact centering of the patient and central ray.
- For a right renal arteriogram, position the patient so that the central ray enters at the level of L2 midway between the center of the spine and the patient's right side.
- For a selective left renal arteriogram, position the patient so that the central ray usually enters at the level of L1 and midway between the center of the spine and the patient's left side (Fig. 26-24).
- Make the exposures. A renal flush aortogram may be accomplished by injecting 25 ml/sec for a 40-ml total volume of contrast medium through a multiple side hole catheter positioned in the aorta at the level of the renal arteries. A representative selective injection is 8 ml/sec for a 12-ml total volume. Imaging for both methods of injections is commonly three to six images per second for 2 to 3 seconds followed by perhaps only one or two nephrogram images made 5 to 10 seconds after the beginning of the injection.

### OTHER ABDOMINAL ARTERIOGRAMS

Other arteries branching from the aorta may be selectively studied to demonstrate anatomy and possible pathologic condition. The positioning for these procedures depends on the area to be studied and the surrounding structures.



## Central Venography

Venous blood in veins flows proximally. Injection into a central venous structure may not opacify the peripheral veins that *anastomose* to it. However, the position of peripheral veins can be indirectly documented by the filling defect from unopacified blood in the opacified central vein. The CIT observes the following guidelines:

- Place the patient in the supine position for either a single-plane AP or PA projection or biplane projections. Move the patient's arms out of the field of view.
- Obtain lateral projections at increased SID, if possible, to reduce magnification.
- Remember that collimation to the long axis of the vena cava improves image quality but may prevent visualization of peripheral or *collateral veins*.

### SUPERIOR VENACAVOGRAM

Venography of the superior vena cava is performed primarily to rule out the existence of thrombus or the occlusion of the superior vena cava. The contrast medium may be injected through a needle or an angiographic catheter introduced into a vein in an antecubital fossa, although superior opacification results from injection through a catheter positioned in the axillary or subclavian vein. Radiographs should include the opacified subclavian vein, brachiocephalic vein, the superior vena cava, and the right atrium (Fig. 26-25). The injection program depends mostly on whether a needle, an angiographic catheter, or a regular catheter is used. A representative program for a catheter injection is 10 to 15 ml/sec for a 30- to 50-ml total volume of contrast medium. Images are produced in both planes, if desired, at a rate of one or two images per second for 5 to 10 seconds and are made at the end of suspended inspiration.

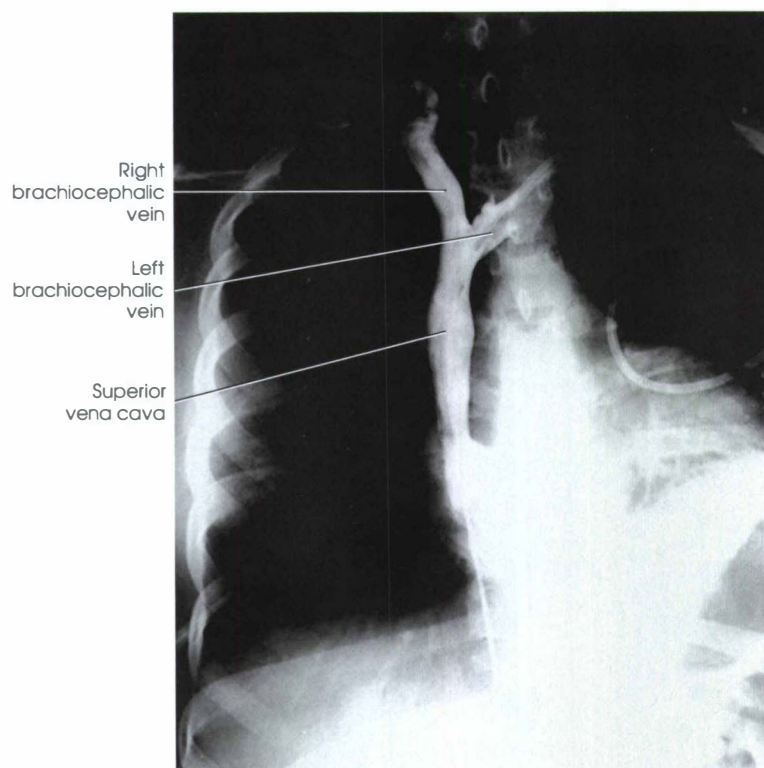


Fig. 26-25 AP superior vena cava.

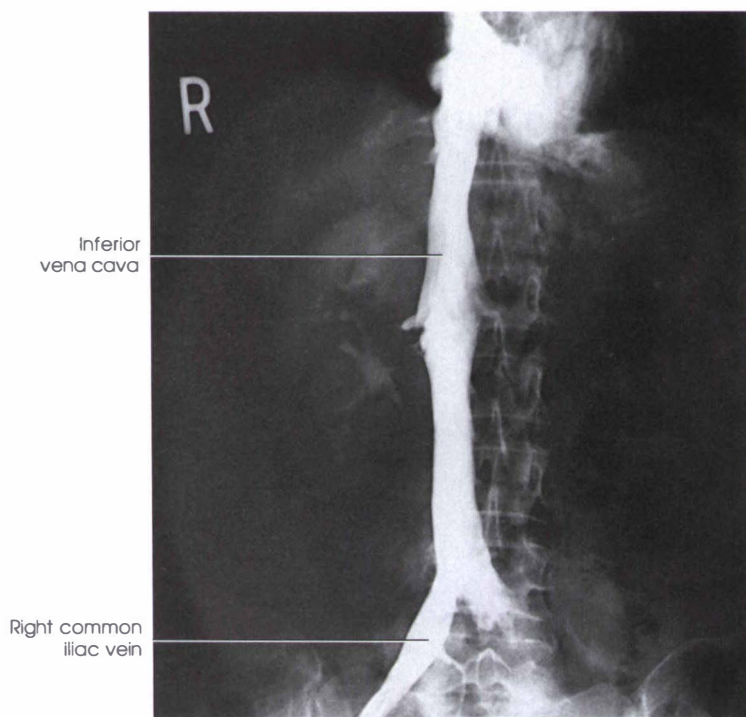


Fig. 26-26 AP inferior vena cava.

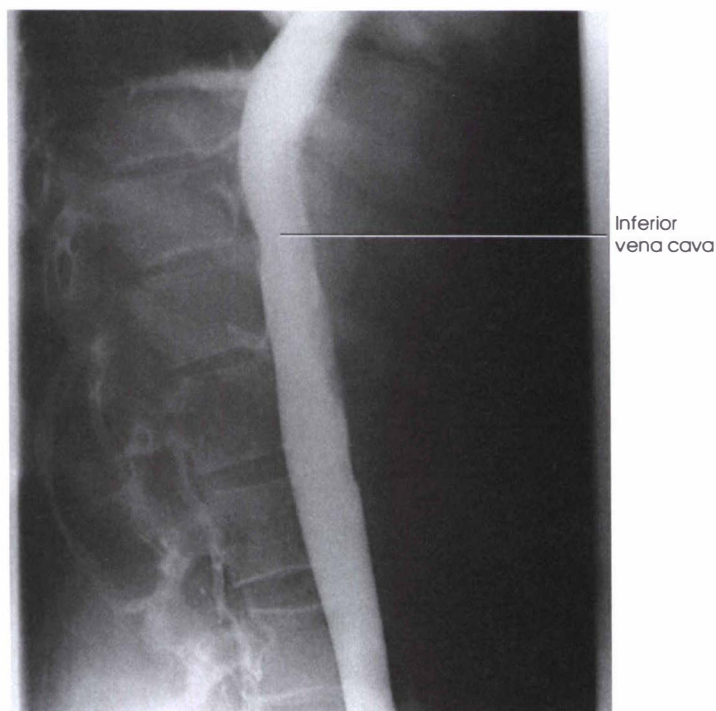


Fig. 26-27 Lateral inferior vena cava.

### INFERIOR VENACAVOGRAM

Venography of the inferior vena cava is performed primarily to rule out the existence of thrombus or the occlusion of the inferior vena cava. The contrast medium is injected through a multiple side hole catheter inserted through the femoral vein and positioned in the common iliac vein or the inferior aspect of the inferior vena cava. Radiographs may need to include the opacified vasculature from the catheter tip to the right atrium (Figs. 26-26 and 26-27). Representative injection and imaging programs are 20 ml/sec for a 40-ml total volume of contrast medium and two images per second for 4 to 8 seconds in both planes. Imaging begins at the end of suspended expiration.



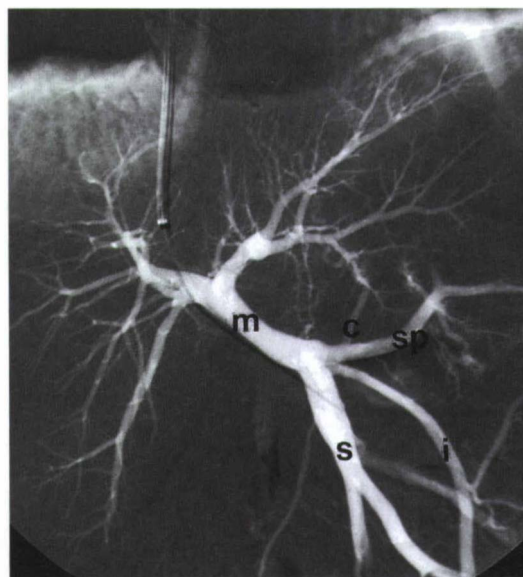
## Selective Visceral Venography

The visceral veins are often visualized by extending the imaging program of the corresponding visceral artery injection. For example, the veins that drain the small bowel are normally visualized by extending the imaging program of a superior mesenteric arteriogram. Portal venography, (Fig. 26-28) can be performed by injecting the portal vein directly from a percutaneous approach, but it is usually accomplished by late-phase imaging of a splenic artery injection or an SMA injection.

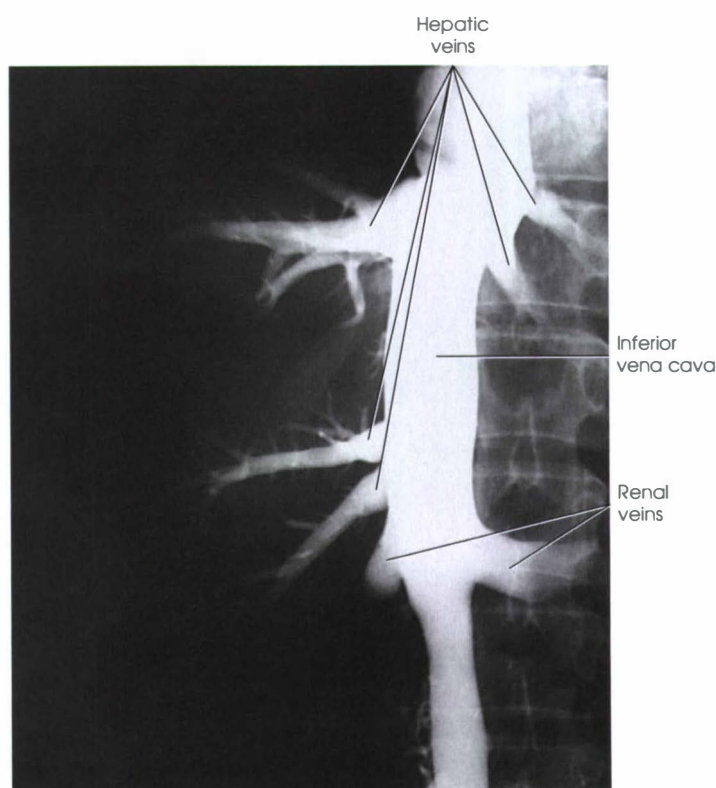
### HEPATIC VENOGRAM

Hepatic venography is usually performed to rule out stenosis or thrombosis of the hepatic veins. These veins are also catheterized to obtain pressure measurements from the interior of the liver. The hepatic veins carry blood from the liver to the inferior vena cava. (The portal vein carries nutrient-rich blood from the viscera to the liver.) The hepatic veins are most easily catheterized from a jugular vein or an upper limb vein approach, but a femoral vein approach may also be used. The CIT follows these steps:

- Place the patient in the supine position for AP or PA projections that include the liver tissue and the extreme upper inferior vena cava (Fig. 26-29).
- Make the exposures. Representative injection and imaging programs are 10 ml/sec for a 30-ml total volume of contrast medium and one image per second for 8 seconds.
- Make exposures at the end of suspended expiration.



**Fig. 26-28** Portal venogram. (m, Main portal v.; s, superior mesenteric v.; i, inferior mesenteric v.; sp, splenic v.; c, coronary varices.)



**Fig. 26-29** Hepatic vein visualization from reflux from an inferior vena cava injection. (Note of reflux into bilateral renal veins.)

### RENAL VENOGRAM

Renal venography is usually performed to rule out thrombosis of the renal vein. The renal vein is also catheterized for blood sampling, usually to measure the production of renin, an enzyme produced by the kidney when it lacks adequate blood supply. The renal vein is most easily catheterized from a femoral vein approach. The following steps are observed:

- Place the patient in the supine position for a single-plane AP or PA projection.

- Center the selected kidney to the image receptor, and collimate the field to include the kidney and area of the inferior vena cava (Fig. 26-30).
- Make the exposures. Representative injection and imaging programs are 8 ml/sec for a 16-ml total volume of contrast medium and two images per second for 4 seconds.
- Make exposures at the end of suspended expiration.

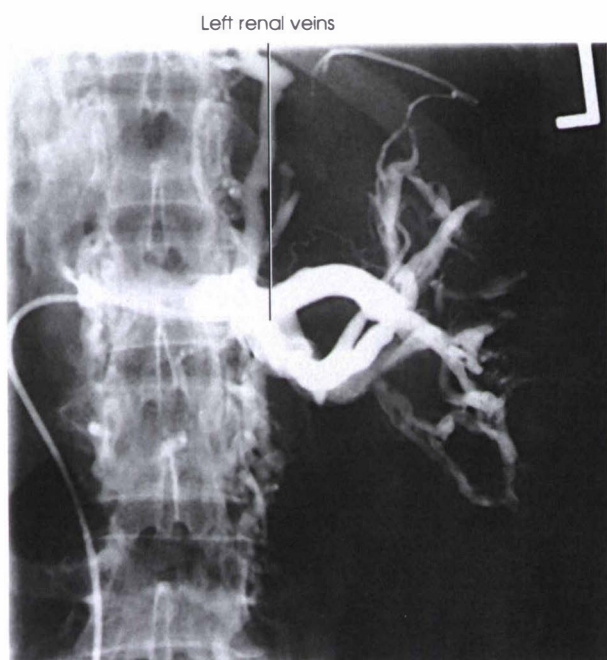


Fig. 26-30 Selective left renal venogram. AP projection.

### Peripheral Angiography

#### UPPER LIMB ANTERIOGRAMS

Upper limb arteriography is most often performed to evaluate traumatic injury, atherosclerotic disease or other vascular lesions. The arteriograms are usually obtained by using the Seldinger technique to introduce a catheter usually at a femoral artery site for selective injection into the subclavian or axillary artery. The contrast medium may also be injected at a more distal site through a catheter. The area to be radiographed may therefore be just a hand or other selected part of the arm, or it may include the entire upper limb and thorax.



Fig. 26-31 Right hand arteriogram (2:1 magnification) showing severe arterioocclusive disease (arrows) affecting digits after cold-temperature injury.



The recommended projection is a true AP projection with the arm extended and the hand supinated. Hand arteriograms may be obtained in the supine or prone arm position (Figs. 26-31 and 26-32). The injection and imaging programs depend on the equipment used. The injection varies from 3 or 4 ml/sec through a catheter positioned distally to 10 ml/sec through a proximally positioned catheter. Imaging using a long cassette changer may be performed with 1- or 2-second delays between exposures. A representative program for a rapid imaging system may be two films per second for 5 seconds followed by one per second for 5 seconds.

### UPPER LIMB VENOGRAMS

Upper limb venography is most often performed to look for thrombosis. The contrast medium is injected through a needle or catheter into a superficial vein at the elbow or wrist. The radiographs should cover the vasculature from the wrist or elbow to the superior vena cava.

The projection and imaging sequence depend on the location of the injection site (Fig. 26-33). If the injection and filling of veins are observed with a fluoroscopic spot-film device, radiographs can be exposed as the vessels opacify. If a Bucky tray or rapid sequence imaging system is used, a series of images with a delay of a few seconds between exposures is normally obtained. Injections may be made by hand, or an automatic injector may be set to deliver a total of 40 to 80 ml at a rate of 1 to 4 ml/sec, depending on whether a needle or catheter is used. If the study is performed with the patient supine, tourniquets positioned proximal to the wrist and elbow will force the contrast medium into the deep veins.



Fig. 26-32 Right subclavian artery injection demonstrating iatrogenic occlusion of radial artery (arrow).

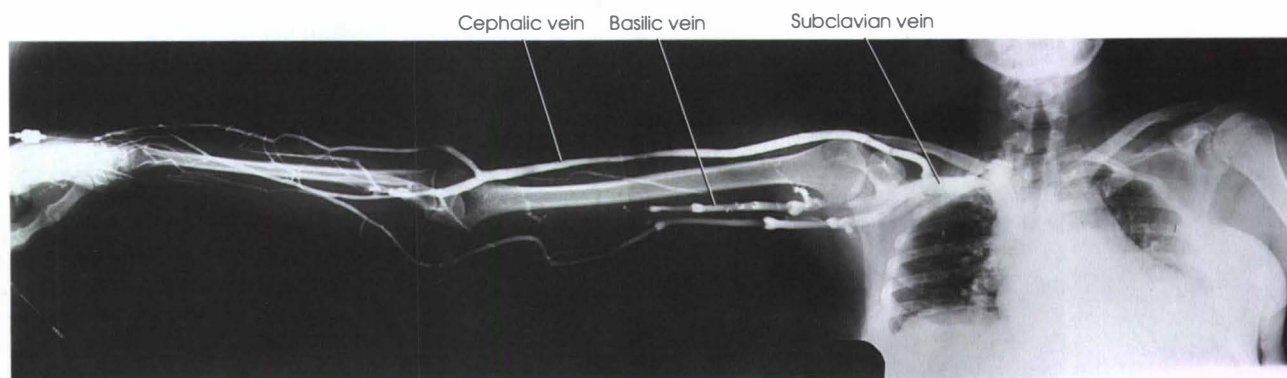
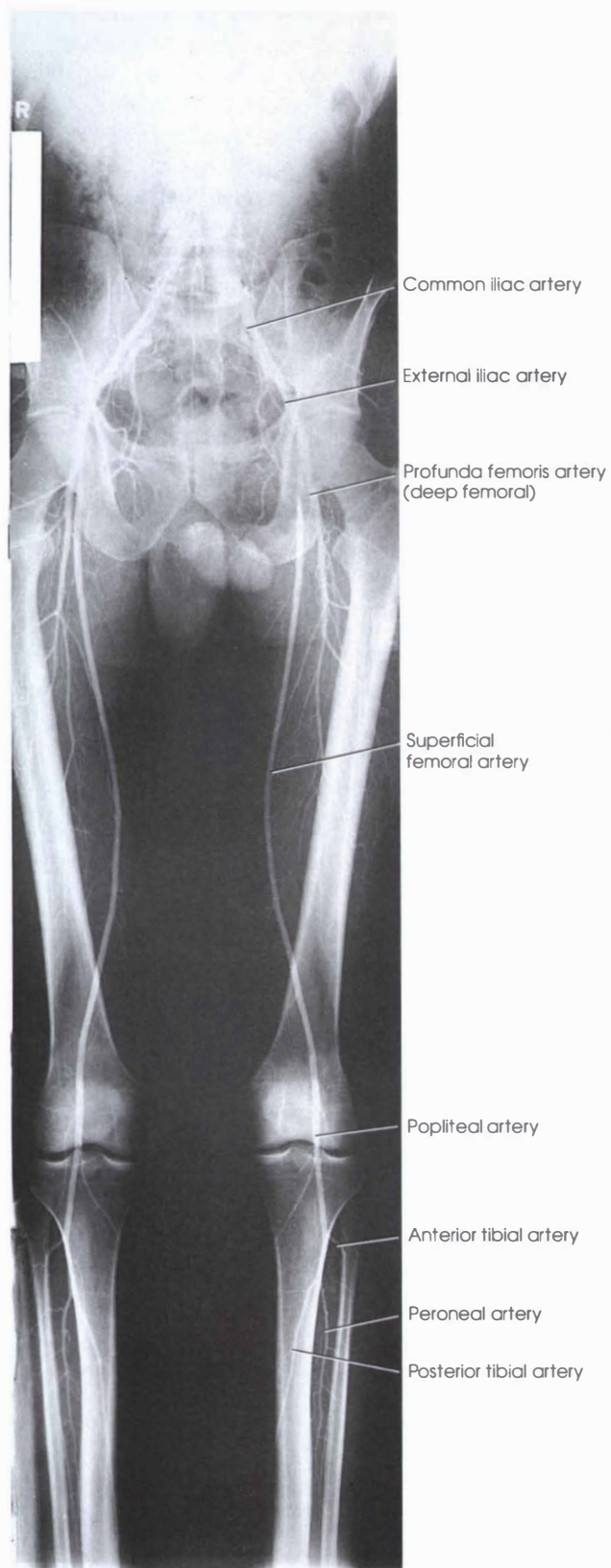
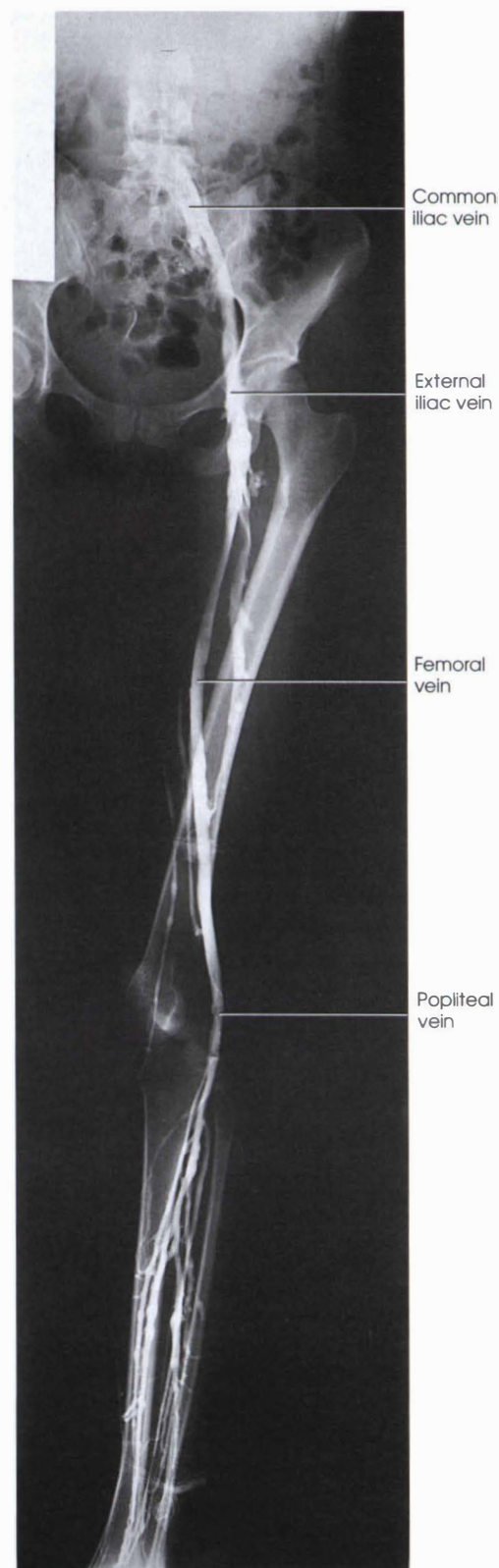


Fig. 26-33 Normal right upper limb venogram.



**Fig. 26-34** Normal abdominal aortogram and bilateral femoral arteriogram in late arterial phase.



**Fig. 26-35** Normal left lower limb venogram.



### Aortofemoral arteriograms

Aortofemoral arteriography is usually performed to determine if atherosclerotic disease is the cause of *claudication*. A catheter is usually introduced into a femoral artery using the Seldinger technique. The catheter tip is positioned superior to the aortic bifurcation so that bilateral arteriograms are obtained simultaneously. When only one leg is to be examined, the catheter tip is placed below the bifurcation, or the contrast medium is injected through a needle placed in the femoral artery. The CIT then observes the following guidelines:

- For a bilateral examination, place the patient in the supine position for single-plane AP projections and center the patient to the midline of the image receptor to include the area from the renal arteries to the ankles.
- Place the patient in the prone position for a translumbar aortic catheterization if needed.
- For either patient position, internally rotate the legs 30 degrees.
- For best results, use a cassette changer with a length of 48 inches (122 cm).
- If the cassette changer is not available, have the cassettes overlap to ensure coverage of all vasculature. Overlapping cassettes can be produced automatically by "stepping" systems with moving tables or C-arms.
- Make exposures of the opacified lower abdominal aorta and aortic bifurcation with the patient in suspended expiration.

Imaging programs vary and are set based on the predicted rate of flow through the long arterial course of the lower limb. Flow through normal arteries may take as little as 10 seconds, whereas flow through severely diseased arteries may take 30 seconds or more. A representative injection program designed to create a long bolus of contrast medium is 10 ml/sec for an 100-ml total volume (Fig. 26-34).

Examinations of a specific area of the leg such as the popliteal fossa or foot are occasionally performed. For these procedures the preferred injection site is usually the femoral artery. AP, lateral, or both projections may be obtained with the patient centered to the designated area.

### LOWER LIMB VENOGRAMS

Lower limb venography is common and is usually performed to rule out thrombosis of the deep veins of the leg. Venograms are usually obtained with contrast medium injected through a needle placed directly into a superficial vein in the foot. The CIT then observes the following guidelines:

- Obtain radiographs with the patient on a tilt table in a semiupright position at a minimum angle of 45 degrees if possible.
- Begin imaging at the patient's ankle, and proceed superiorly to include the inferior vena cava as the injection continues.
- Without fluoroscopy, usually obtain AP projections with the leg internally rotated 30 degrees to include the entire area of interest (Fig. 26-35). Exact positioning is often determined with fluoroscopic direction.
- Perform lateral projections if needed.
- If imaging is performed with the patient supine, apply tourniquets just proximal to the ankle and knee to force filling of the deep veins in the leg.
- Usually, expose serial radiographs 5 to 10 seconds apart. Injections may be made by hand, or an automatic injector may be set to deliver 1 or 2 ml/sec for a total of 50 to 100 ml.

### Angiography in the Future

Visceral and peripheral angiography is a dynamic area that challenges angiographers to keep abreast of new techniques and equipment. New diagnostic modalities that reduce or eliminate irradiation may be developed that may replace a number of current angiographic procedures. Some diagnostic information, however, can be obtained only through conventional angiographic methods. Consequently, angiography will continue to be used to examine vasculature and, through therapeutic procedures, to provide beneficial treatment. However, non-invasive imaging techniques such as MR angiography or CT angiography, are now being utilized more. These less invasive procedures may eliminate some diagnostic angiographic procedures. It may eliminate diagnostic procedures but at this point, therapeutic procedures continue.

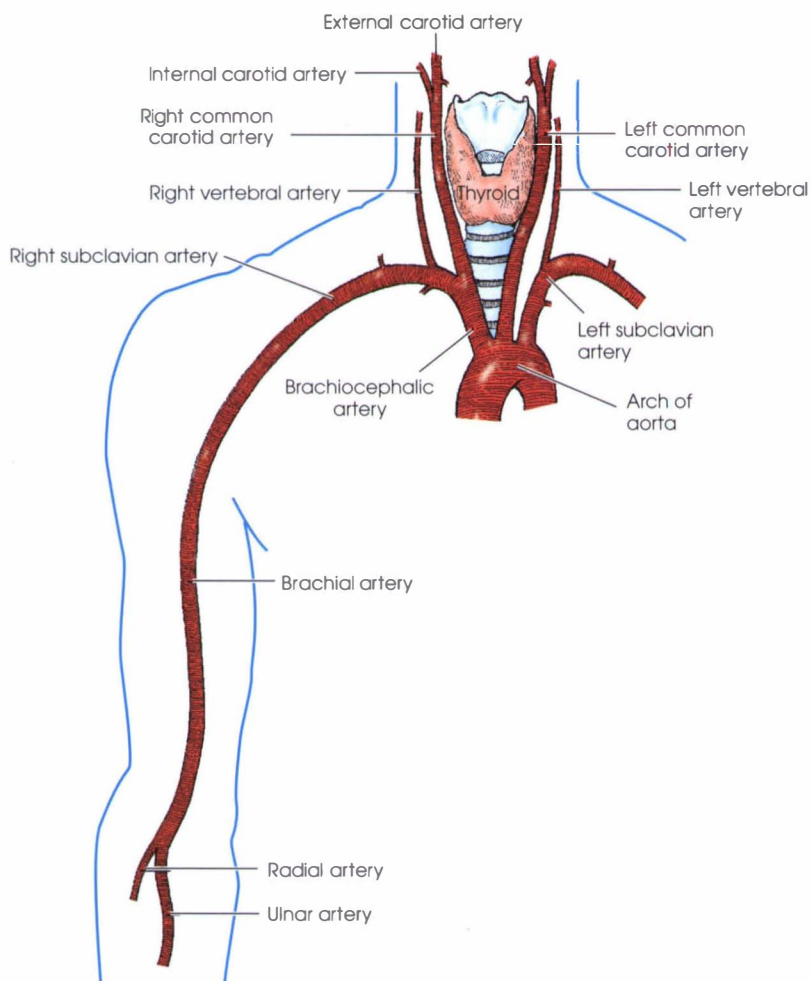


Fig. 26-36 Major arteries of upper chest, neck, and arm.

## Cerebral Anatomy

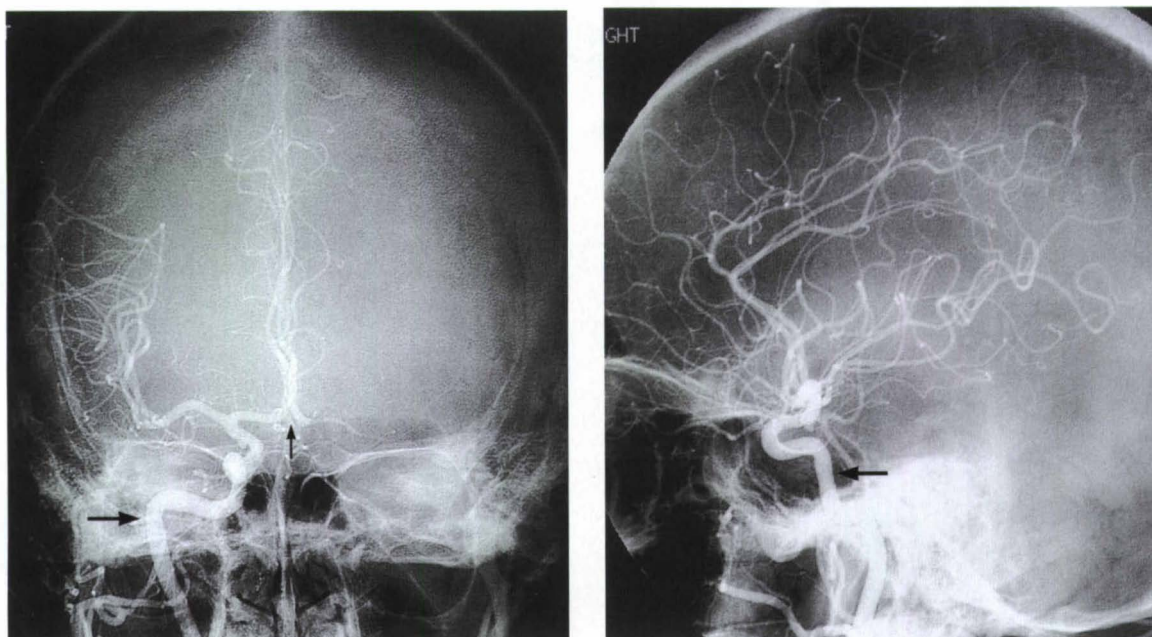
*Cerebral angiography* is the radiologic/angiographic examinations of the blood vessels of the brain. The procedure was introduced by Egas Moniz<sup>1</sup> in 1927. It is performed to investigate intracranial vascular lesions such as aneurysms, AVMs, tumors, and atherosclerotic or stenotic lesions.

The brain is supplied by four trunk vessels or great vessels (Fig. 26-36): the right and left common carotid arteries, which supply the anterior circulation; and the right and left vertebral arteries, which supply the posterior circulation. These paired arteries branch from the arch of the aorta and ascend through the neck.

<sup>1</sup>Egas Moniz AC: L'encéphalographie artérielle, son importance dans la localisation des tumeurs cérébrales, *Rev Neurol* 2:72, 1927.



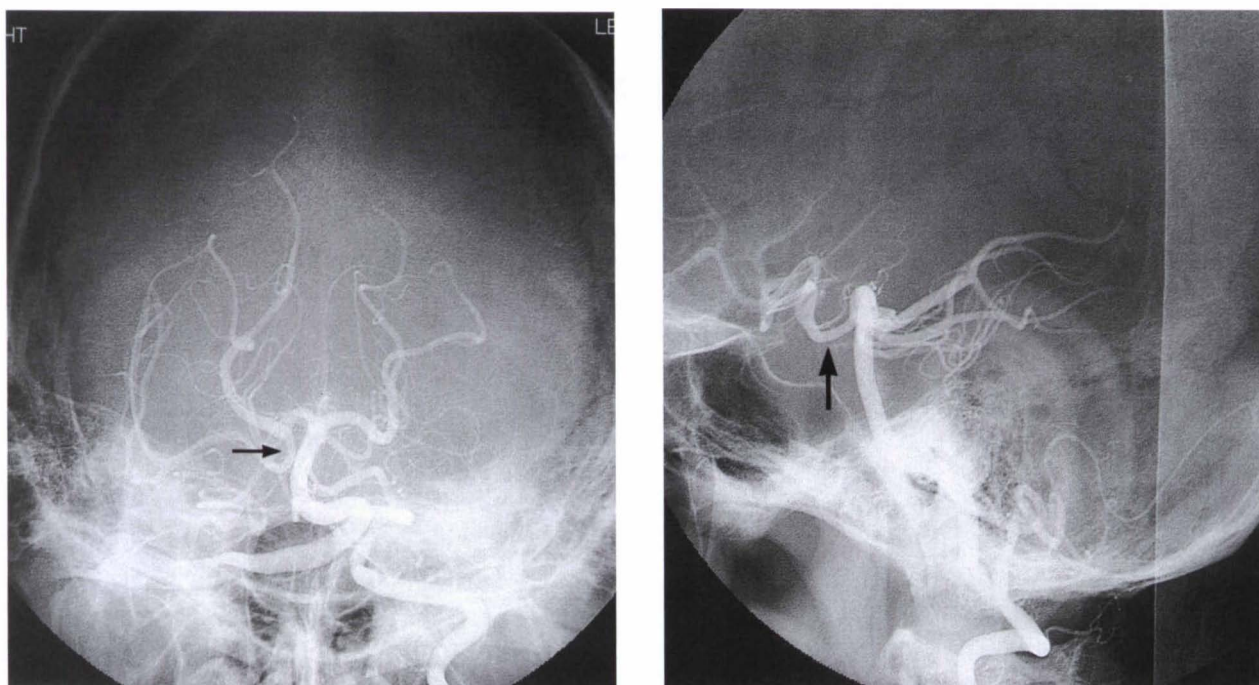
The first branch of the aortic arch is the *innominate artery* or the *brachiocephalic artery*. It then bifurcates into the right common carotid and the right subclavian artery. The second branch of the aortic arch is the left common carotid, followed by the left subclavian artery. Each of the vessels originate directly from the aortic arch. Both vertebral arteries most commonly take their origins from the subclavian arteries. Although this branching pattern is common in most patients, there can be some *anomalous* origins of these great vessels. Each common carotid artery passes superiorly and somewhat laterally alongside the trachea and larynx to the level of C4. There each divides into internal and external carotid arteries. The external carotid artery contributes blood supply to the extracranial and extra-axial circulation. There can be some collateral circulation into the internal carotid circulation in some situations. The internal carotid artery enters the cranium through the carotid foramen of the temporal bone and then bifurcates into the anterior and middle cerebral arteries (Fig. 26-37). These vessels in turn branch and rebranch to supply the anterior circulation of the respective hemisphere of the brain.



**Fig. 26-37** Right common carotid artery injection demonstrating right internal carotid artery (arrows) and anterior cerebral blood circulation including reflux across the anterior communication artery (small arrow).

The vertebral arteries ascend through the cervical transverse foramina and then pass medially to enter the cranium through the foramen magnum. The vertebral arteries unite to form the basilar artery, which, after a short superior course along the posterior surface of the dorsum sellae, bifurcates into the right and left posterior cerebral arteries. The blood supply to the posterior fossa (cerebellum) originates from the vertebral and basilar arteries (Fig. 26-38).

The anterior and posterior cerebral arteries are connected by communicating arteries at the level of the midbrain to form the *circle of Willis*. The anterior communicating artery forms an anastomosis between the anterior cerebral arteries, which communicate between the right and left hemispheres. The right and left posterior communicating arteries each form an anastomosis between the internal carotid artery and the posterior cerebral artery connecting the anterior and posterior circulation.



**Fig. 26-38** Left vertebral artery injection demonstrating the posterior cerebral blood circulation, including reflux into the posterior communicating artery (arrows).



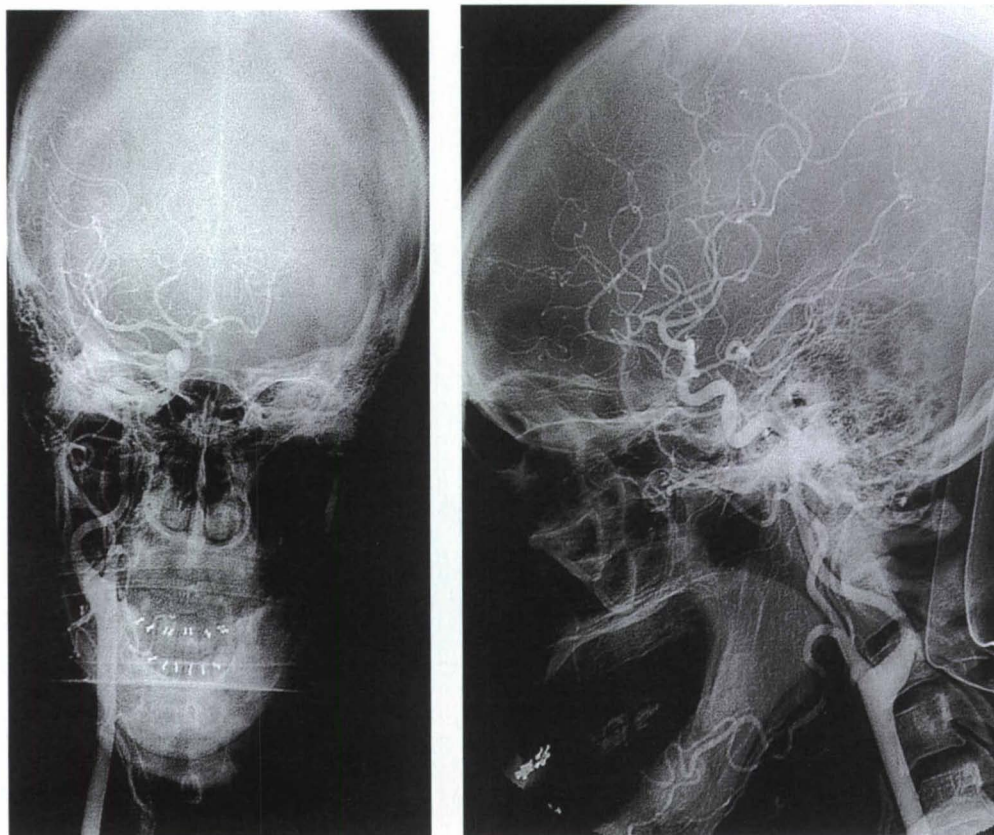
## Cerebral Angiographic Studies

### TECHNIQUE

Cerebral angiography should be performed only in facilities equipped to produce studies of high technical quality with minimal risk to the patient. The ability to obtain rapid-sequence biplane images with automatic injection represents the minimum standard. This equipment is available in all major medical centers and in most large hospitals.

Cerebral angiography is most commonly performed from a transfemoral approach (Fig. 26-43); however, a brachial or axillary artery approach can be employed. Selective catheterization techniques also allow the internal and external carotid circulation (Fig. 26-39) to be studied separately, which is useful in delineating the blood supply of some forms of cerebral tumors and vascular malformations.

The final position of the catheter depends on the information sought from the angiographic study. When atherosclerotic disease of the extracranial carotid, subclavian, and vertebral arteries is being evaluated, injection of the aortic arch with imaging of the extracranial portion of these vessels is an appropriate way to begin.



**Fig. 26-39** Right common carotid artery injection demonstrating intracranial and extracranial circulation.



Fig. 26-40 Right internal carotid injection, lateral projection, demonstrates arterial phase of circulation, note the posterior communicating artery (arrow).



Fig. 26-41 Right internal carotid injection, lateral projection, demonstrates capillary phase of carotid circulation.

## CIRCULATION TIME AND IMAGING PROGRAM

Egas Moniz<sup>1</sup> stated that the transit time of the cerebral circulation is only 3 seconds for the blood to circulate from the internal carotid artery to the jugular vein, with the circulation time being slightly prolonged by the injected contrast solution. Greitz,<sup>2</sup> who measured the cerebral circulation time as "the time between the points of maximum concentration (of contrast medium) in the carotid siphon and in the parietal veins," found a normal mean value of 4.13 seconds. This time is a highly important factor in cerebral angiography.

Certain pathologic conditions significantly alter the cerebral circulation time. *Arteriovenous malformations (AVMs)* shorten the transit time or arterial vasospasm may cause a considerable delay.

A standard radiographic program should include a radiograph taken before the arrival of contrast material to serve as a subtraction mask (see p. 87) and rapid-sequence images at one and one-half to three images per second in the AP and lateral projections during the early, or arterial, phase (first  $1\frac{1}{2}$  to  $2\frac{1}{2}$  seconds) of the arteriogram (Fig. 26-40). After the arterial phase, imaging may be slowed to one image per second for the capillary, or parenchymal, phase (Fig. 26-41) and maintained at one image per second or every other second for the venous phase (Fig. 26-42) of the angiogram. The entire program should cover 7 to 10 seconds, depending on the preference of the angiographer. The imaging program must be tailored to demonstrate the suspected pathologic condition.

Injection rates and volumes through the catheter are coupled with the imaging program, usually by automatic means. Injections at rates of 5 to 9 ml/sec for 1 to 2 seconds are most often employed in the cerebral vessels, with variations dependent on vessel size and the patient's circulatory status.

<sup>1</sup>Egas Moniz AC: L'angiographie cérébrale, Paris, 1934, Masson & Cie.

<sup>2</sup>Greitz T: A radiologic study of the brain circulation by rapid serial angiography of the carotid artery, *Acta Radiol Suppl* 140:Nov, 1956.



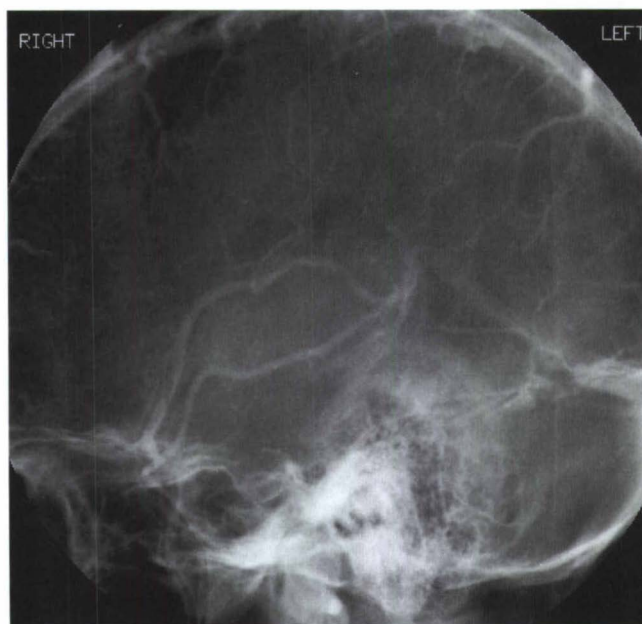
## EQUIPMENT

Rapid-sequence biplane imaging with either film or DSA electronically coupled with an automatic injector is employed almost universally in cerebral angiography.

Collimating to the area of the head and neck is essential for improving image quality in the nonmagnified study. The standard tube collimator may be used for this purpose, or lead cutout diaphragms may also be positioned on the collimator. These diaphragms may have openings in the shape of a circle or a "keyhole." The keyhole diaphragm openings are rounded in the area of the cranium and taper inward in the area of the neck. The frontal and lateral keyhole diaphragms are each designed to resemble the shape of the head and neck in their respective images.

## PREPARATION OF PATIENT

Other than withholding the preceding meal, preliminary preparation depends on the patient's condition and is accordingly determined by the radiologist and the referring physician. Whenever possible, adult patients are examined under local anesthesia in conjunction with conscious sedation. Adequate sedation minimizes the intensity of the burning pain felt along the course of the vessel and the areas supplied by it during the rapid injections of iodinated medium. It is imperative that conscious patients receive a careful explanation of what to expect during the procedure and what is expected of them. This explanation is essential for the successful completion of the procedure.



**Fig. 26-42** Right internal carotid injection, lateral projection, demonstrates venous phase of circulation.

## PREPARATION OF EXAMINING ROOM

It cannot be stated too often that the angiographic suite and every item in it should be scrupulously clean. The room should be fully prepared, with every item needed or likely to be needed on hand before the patient is admitted. Cleanliness and advance preparation are of vital importance in procedures that must be carried out under aseptic conditions. The CIT should observe the following guidelines in preparing the room:

- Check the angiographic equipment and all working parts of the equipment, and adjust the controls for the exposure technique to be employed.
- Place identification markers and all accessories in a convenient location.
- Have restraining bands available for application in combative patients.
- Adapt immobilization of the head (by suitable strapping) to the type of equipment employed.
- Make arrangements for immediate image processing as the procedure proceeds.

The sterile and nonsterile items required for introduction of the contrast medium vary according to the method of injection. The supplies specified by the interventionalist for each procedure should be listed in the angiographic procedure book. Sterile trays or packs, set up to specifications, can usually be obtained from the central sterile-supply room. Otherwise, it is the responsibility of a qualified member of the interventional team to prepare them. Extra sterile supplies should always be on hand in case of a complication. Preparation of the room includes having life-support and emergency equipment immediately available.

## RADIATION PROTECTION

As in all radiographic examinations, the patient is protected by filtration totaling not less than 2.5 mm of aluminum, by sharp restriction of the beam of radiation to the area being examined, and by avoidance of repeat exposures. In angiography, each repeated exposure necessitates repeated injection of the contrast material. For this reason, only skilled and specifically educated CITs should be assigned to take part in these examinations.

Angiography suites should be designed to allow observation of the patient at all times as well as to provide adequate protection to the physician and radiology personnel. These goals are usually accomplished with leaded glass observation windows.

## POSITIONING FOR EXAMINATION

### Position of patient

In positioning the patient, the CIT observes the following steps:

- Place the patient in the supine position.
- Regardless of whether the patient is awake, place suitable supports under points of strain (small of the back, knees, and ankles).
- Apply wrist restraints and compression bands across the body as indicated by the patient's condition.
- Although the catheter is unlikely to be unseated during positioning, exercise care to prevent excessive patient motion, especially with extremely selective studies. General anesthesia may be required for certain procedures to help prevent any movement of the patient.

### Position of head

The centering and angulation of the central ray required for demonstration of the anterior circulation differ from those required for demonstration of the posterior circulation. The same head position is used for the basic AP and lateral projections of both regions. The following steps are observed:

- For the initial right-angle studies, center the head to both the AP and lateral image receptors.
- Adjust the patient's head to place its midsagittal plane exactly perpendicular to the headrest and consequently exactly parallel with the laterally placed image receptor.
- Place the infraorbitomeatal line (IOML) perpendicular to the horizontal plane when positioning is manually accomplished.
- Angle the central ray for caudally inclined AP and AP oblique projections from the vertically placed IOML, or adjust the central ray so that it is parallel to the floor of the anterior fossa, as indicated by a line extending from the supraorbital margin to a point  $\frac{3}{4}$  inch (1.9 cm) superior to the EAM.

In this chapter, head positioning is presented as if the image receptors were fixed in the horizontal and vertical planes. This necessitates the use of facial landmarks for precise positioning of the head in relation to the central ray to achieve certain projections. However, in some angiographic suites fluoroscopy can be used to determine the final position of the head and the angulation of the central ray required to achieve the desired image.

Frontal projections are described in this section as AP projections, but equivalent PA projections also exist. Many angiographic imaging systems place the image receptor above the tabletop and the x-ray tube below. Because patients usually lie supine for cerebral angiography, the central ray, coming from below, enters the posterior cranium and exits the anterior cranium on its course to the image receptor. The position of the central ray results in PA projections equivalent to the AP projections described.

The literature on cerebral angiography contains numerous position variations concerning the degree of central ray angulation, the base from which the central ray should be angled or the line that it should parallel, and the degree of part rotation for oblique studies. This chapter discusses the most frequently employed images and reasonably standard specifications for obtaining them.

The number of radiographs required for satisfactory delineation of a lesion depends on the nature and location of the lesion. Oblique projections and/or variations in central ray angulation are used to separate the vessels that overlap in the basic positions and to evaluate any existing abnormality.



## Aortic Arch Angiogram (for Cranial Vessels)

An aortic arch angiogram is most commonly obtained to visualize atherosclerotic or occlusive disease of the extracranial carotid, vertebral, and subclavian arteries. A multiple side hole catheter is positioned in the ascending thoracic aorta so that the subsequent injection fills all of the vessels simultaneously.

### SIMULTANEOUS BIPLANE OBLIQUE PROJECTIONS

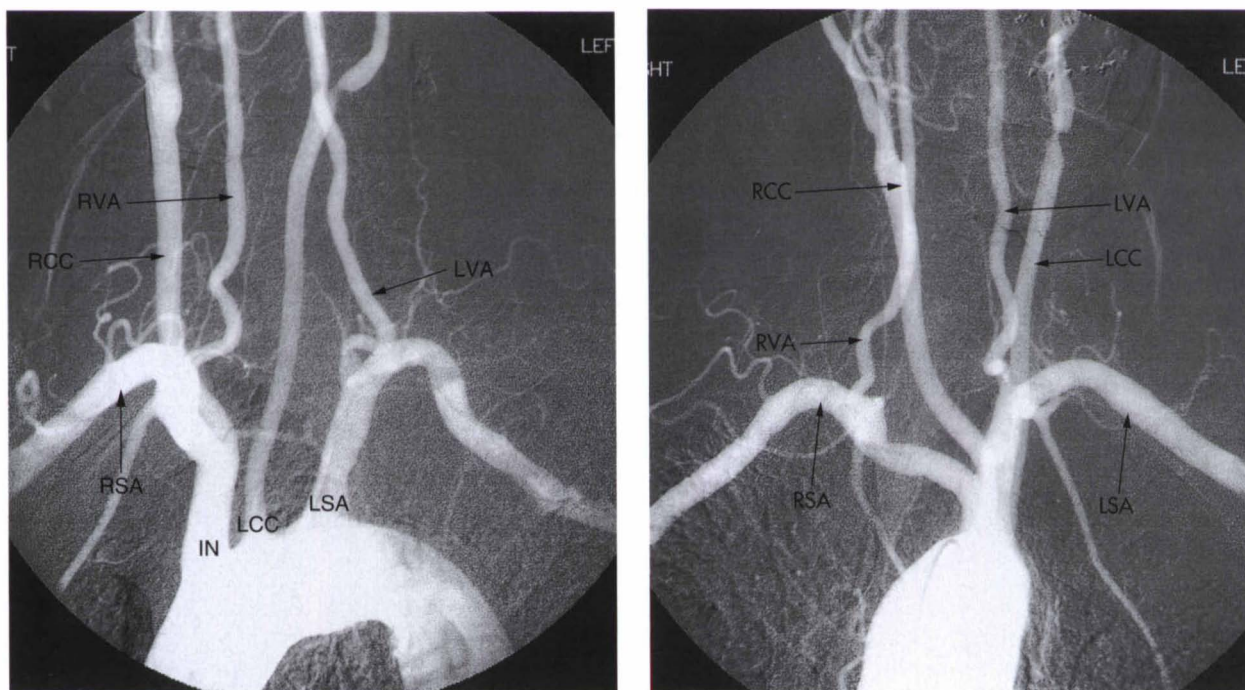
For best results, simultaneous biplane oblique projections are produced so that superimposition of vessels is minimized (Fig. 26-43).

The CIT observes the following steps:

- Place the patient in a 35-degree RPO position on the tabletop, with the mid-sagittal plane of the head either perpendicular to the AP image receptor or in an RPO position. This patient position opens the aortic arch and the origins of the great vessels for the AP oblique projection frees the carotid and vertebral arteries from superimposition.
- Raise the patient's chin to superimpose the inferior margin of the mandible onto the occiput so that as much of the neck as possible is exposed in the frontal radiograph.
- Move the patient's shoulders inferiorly so that they are removed as much as possible from the lateral image.

- If possible, use offset biplane imaging systems for this procedure.
- Position the lateral image receptor similarly to the AP projection to get another image of the origins of the great vessels.
- For the AP and lateral projection, direct the central ray perpendicular to the center of the image receptor to enter the patient at a level  $1\frac{1}{4}$  inch (3 cm) superior to the sternal angle.

A representative injection program for an aortic arch examination is 15 to 20 ml/sec for a total volume of 35 to 40 ml. A representative imaging program is two to three images per second in each plane for 4 seconds. Because subtraction images are frequently produced from aortic arch angiograms, the initial images should be exposed before the injection begins. An alternative imaging program exposes one image in each plane, pauses 1 second as the injection begins, and then continues with two to three images per second for 3 seconds.



**Fig. 26-43** Digital subtracted images of the thoracic aortogram demonstrates the origins of the great vessels.

## Anterior Circulation

### LATERAL PROJECTION

The CIT observes the following steps:

- Center the patient's head to the vertically placed image receptor.
- Extend the patient's head enough to place the IOML perpendicular to the horizontal.
- Adjust the patient's head to place the midsagittal plane vertical and thereby parallel with the plane of the image receptor.
- Adapt immobilization to the type of equipment being employed.
- Perform lateral projections of the anterior, or carotid, circulation with the central ray directed horizontally to a point slightly cranial to the auricle and midway between the forehead and the occiput. This centering allows for patient variation (Figs. 26-44 to 26-46).

**NOTE:** See Fig. 26-67 for assistance in identifying the cerebral vessels in the image.

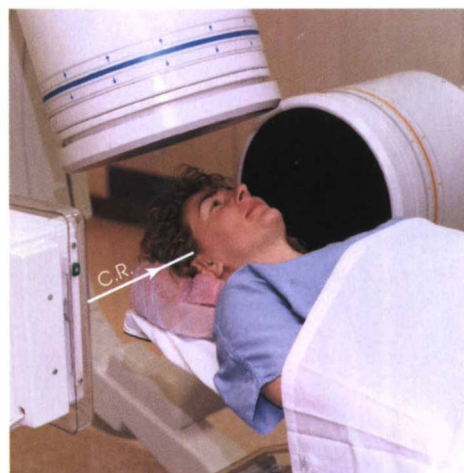


Fig. 26-44 Cerebral angiogram: lateral projection as part of a biplane setup.

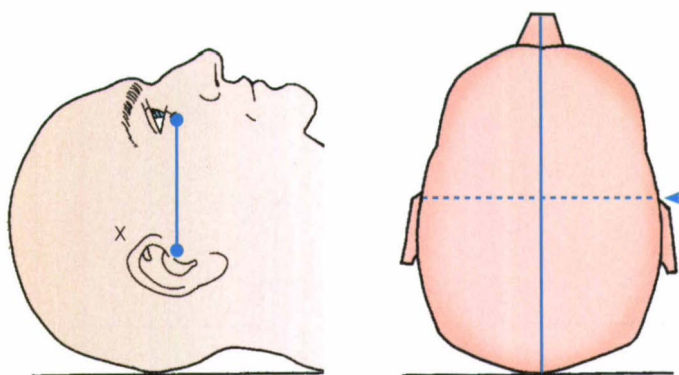


Fig. 26-45 Lateral projection.

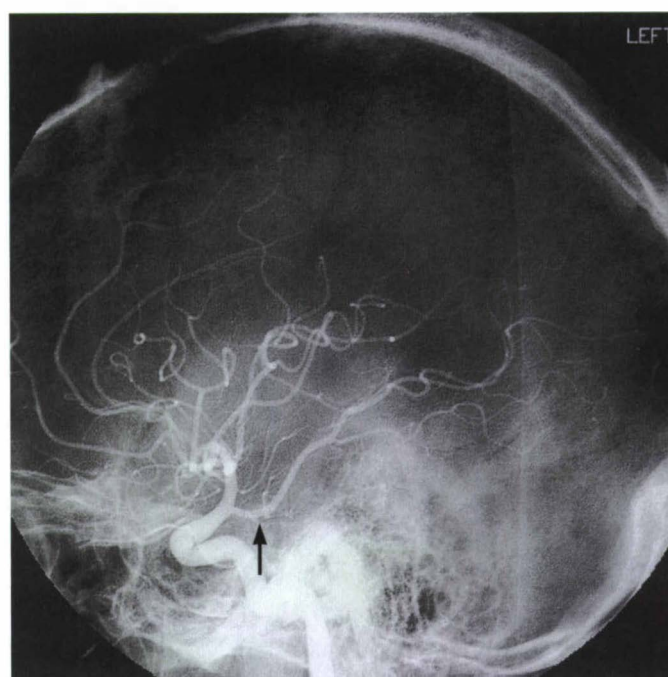


Fig. 26-46 Left internal carotid artery injection. Cerebral angiogram: lateral projection demonstrating anterior circulation. Note the posterior communicating artery (arrow).





Fig. 26-47 Carotid angiogram: PA axial (supraorbital) projection.

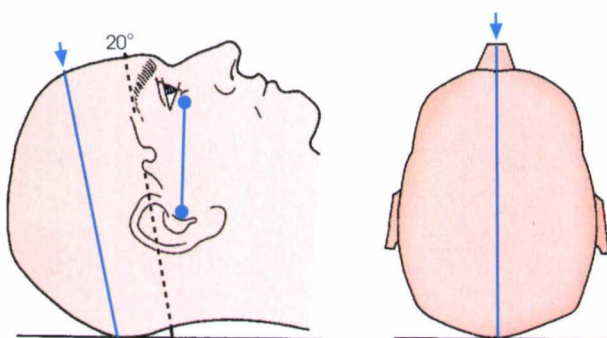


Fig. 26-48 AP axial (supraorbital).



Fig. 26-49 Left common carotid artery, demonstrates AP axial (supraorbital) projection. Arterial phase of circulation.

### AP AXIAL PROJECTION (SUPRAORBITAL)

The CIT observes the following steps:

- Adjust the patient's head so that its midsagittal plane is centered over and perpendicular to the midline of the grid and so that it is extended enough to place the IOML vertical.
- Immobilize the patient's head.
- Keep in mind that achieving the goal in this angiogram requires superimposition of the supraorbital margins on the superior margin of the petrous ridges so that the vessels are projected above the floor of the anterior cranial fossa.
- To obtain this result in the majority of patients, direct the central ray 20 degrees caudal for the AP axial or 20 degrees cephalad for the PA axial projection along a line passing  $\frac{3}{4}$  inch (1.9 cm) superior to and parallel with a line extending from the supraorbital margin to a point  $\frac{3}{4}$  inch (1.9 cm) superior to the external acoustic meatus (EAM); the latter line coincides with the floor of the anterior fossa (Figs. 26-47 to 26-49).



### AP AXIAL OBLIQUE PROJECTION (SUPRAORBITAL)

The following steps are observed:

- Maintain the preceding position for the patient's head, but rotate the head approximately 30 degrees away from the injected side, or angle the central ray 30 degrees toward the injected side.
- Direct the central ray 20 degrees caudad (Figs. 26-50 and 26-51).

### AP AXIAL PROJECTION (TRANSORBITAL)

The CIT observes the following steps:

- Adjust the patient's head for the basic AP projection.

- Direct the central ray through the mid-orbits at an average angle of 20 degrees cephalad. The central ray should coincide with a line passing through the center of the orbit and a point about  $\frac{3}{4}$  inch (1.9 cm) superior to the auricle of the ear (Figs. 26-52 and 26-53).

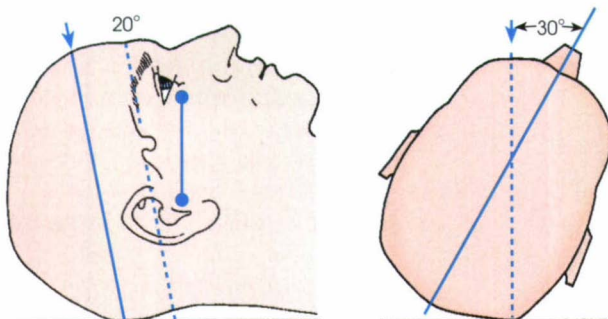


Fig. 26-50 AP axial oblique (supraorbital) projection.



Fig. 26-51 Right common carotid artery injection demonstrates AP axial oblique (supraorbital) projection.

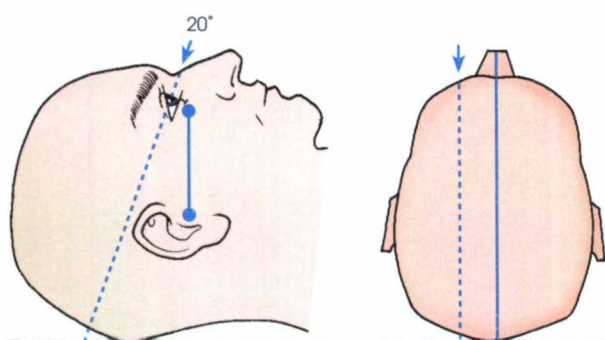


Fig. 26-52 AP axial (transorbital) projection.

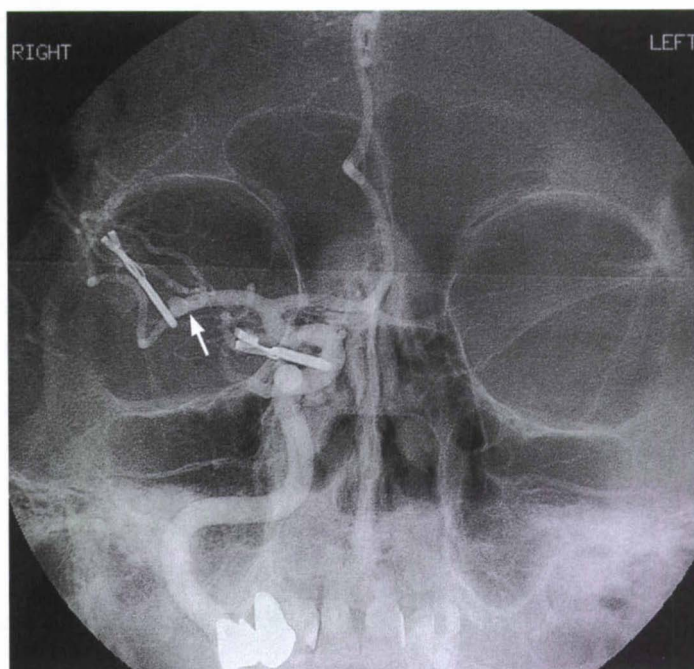


Fig. 26-53 Right internal carotid artery injection demonstrates: AP axial (transorbital) projection note the MCA aneurysm (arrow).

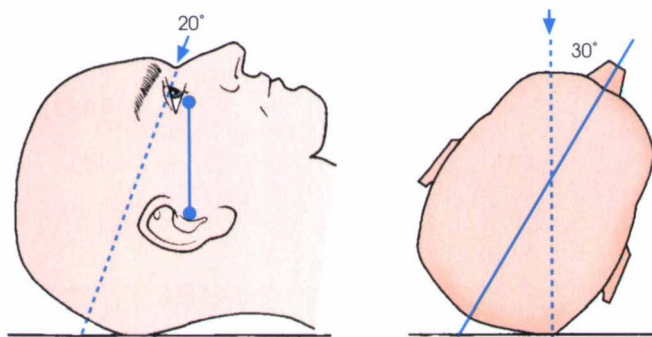


Fig. 26-54 AP axial oblique (transorbital) projection.

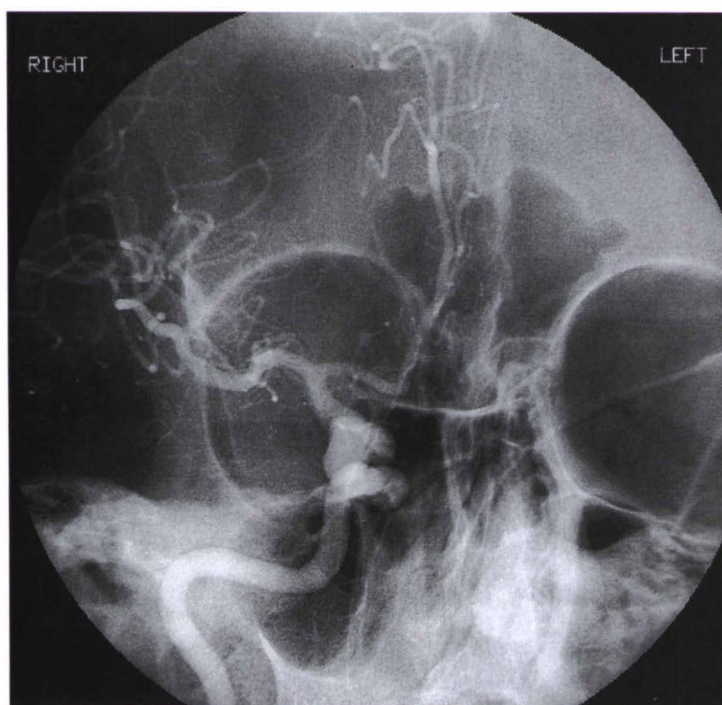


Fig. 26-55 Right internal carotid artery injection demonstrates: AP axial oblique (transorbital) projection.

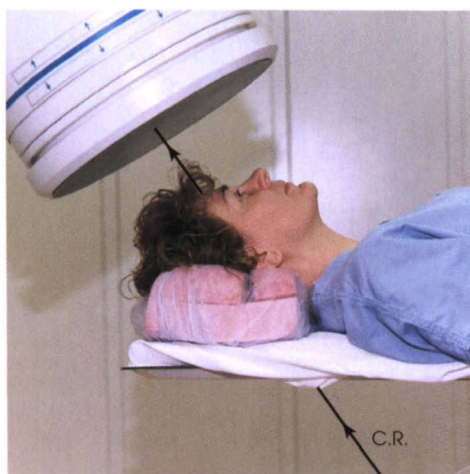


Fig. 26-56 PA axial projection.

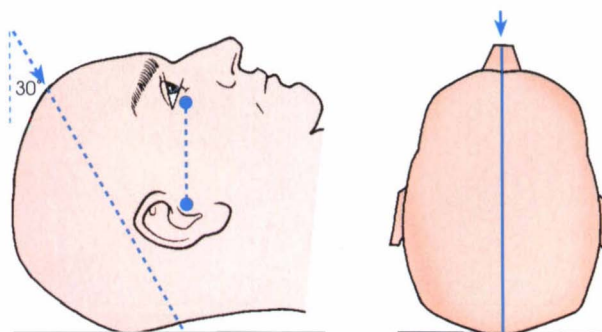


Fig. 26-57 AP axial projection.

### AP AXIAL OBLIQUE PROJECTION (TRANSORBITAL)

The oblique transorbital projection demonstrates the internal carotid bifurcation and the anterior communicating and middle cerebral arteries within the orbital shadow. The steps are as follows:

- From the position for the basic AP transorbital projection, rotate the patient's head approximately 30 degrees away from the injected side, or angle the central ray 30 degrees toward the injected side.
- Angle the central ray 20 degrees cephalad and center it to the midorbit of the uppermost side (Figs. 26-54 and 26-55).

### AP AXIAL AND AP OBLIQUE PROJECTIONS

AP axial and/or AP axial oblique projections are used in carotid angiography, when indicated, for further evaluation of vessel displacement or of aneurysms.

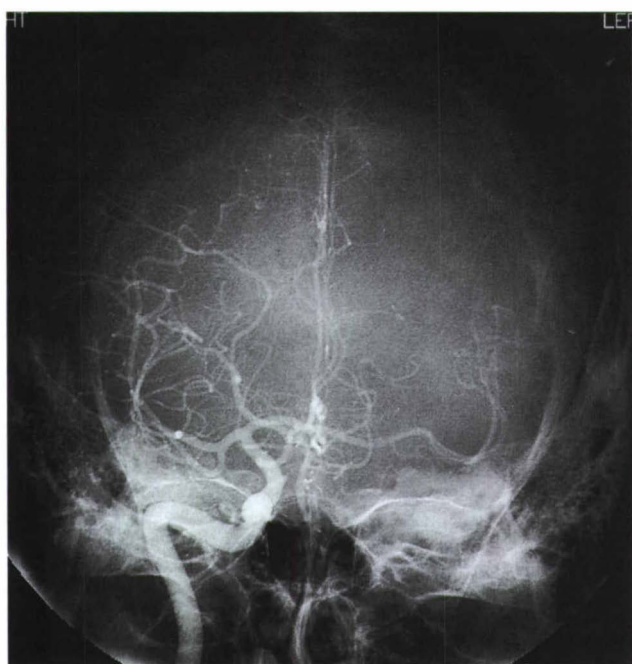
For an AP axial projection, the following steps are observed:

- Adjust the patient's head in the basic AP position.
- Direct the central ray to the region approximately 1½ inches (3.8 cm) superior to the glabella at an average angle of 30 degrees caudad for the AP axial or 30 degrees cephalad for the PA axial projection. The central ray exits at the level of the EAM (Figs. 26-56 to 26-58).

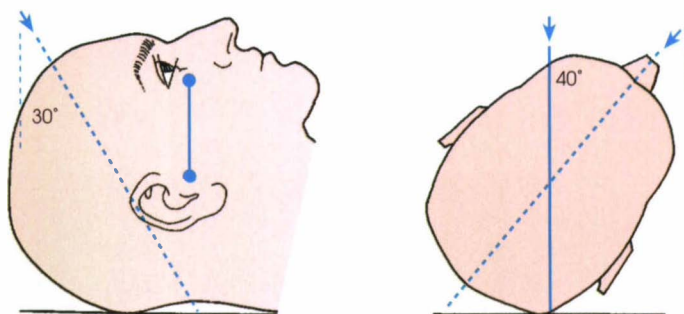
For an AP axial oblique projection, the following steps are observed:

- Rotate the patient's head 35 to 45 degrees away from the injected side, or angle the central ray 35 to 45 degrees toward the injected side.
- Angle the central ray 30 degrees caudad (Figs. 26-59 and 26-60).





**Fig. 26-58** Right internal carotid artery injection demonstrates: AP axial projection.



**Fig. 26-59** AP axial oblique projection.



**Fig. 26-60** Left internal carotid artery injection demonstrates: AP axial oblique projection.



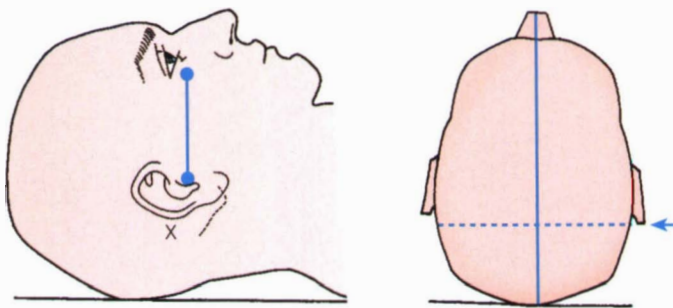


Fig. 26-61 Lateral projection for posterior circulation.

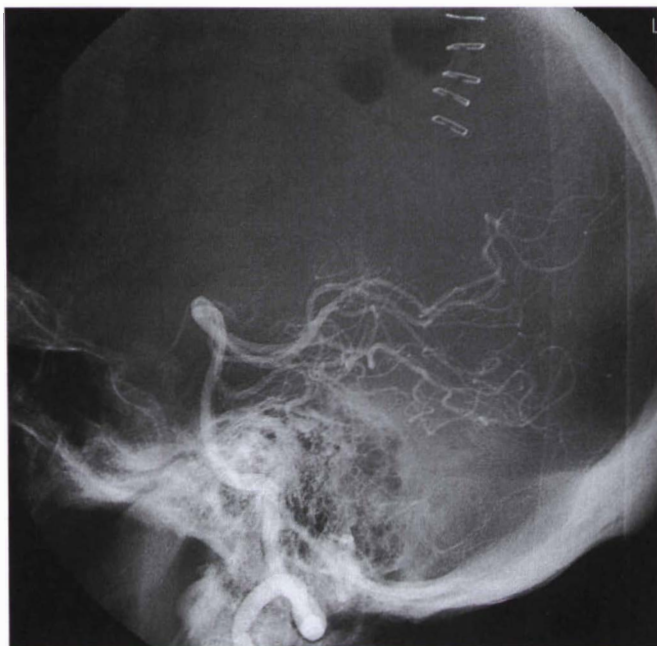


Fig. 26-62 Right vertebral artery injection demonstrates: lateral projection showing verte-brobasilar system.

## Posterior Circulation

### LATERAL PROJECTION

The CIT observes the following steps:

- Center the patient's head to the vertically placed image receptor.
- Extend the patient's head enough to place the IOML perpendicular to the horizontal plane, and then adjust the head to place the midsagittal plane vertical and thereby parallel with the plane of the image receptor.
- Rigidly immobilize the patient's head.
- Perform lateral projections of the posterior, or vertebral, circulation with the central ray directed horizontal to the mastoid process at a point about  $\frac{3}{8}$  inch (1 cm) superior to and  $\frac{3}{4}$  inch (1.9 cm) posterior to the EAM
- Restrict the exposure field to the middle and posterior fossae for lateral studies of the posterior circulation (Figs. 26-61 and 26-62). Inclusion of the entire skull is neither necessary nor, from the standpoint of optimal technique, desirable.

## AP AXIAL PROJECTION

The following steps are observed:

- Adjust the patient's head so that the midsagittal plane is centered over and perpendicular to the midline of the grid, and extend the head enough so that the IOML is vertical.
- Immobilize the patient's head.
- Direct the central ray to the region approximately  $1\frac{1}{2}$  inches (3.8 cm) superior to the glabella at an angle of 30 to 35 degrees caudad. The central ray exits at the level of the EAM. For this projection the supraorbital margins are positioned approximately  $\frac{3}{4}$  inch (1.9 cm) below the superior margins of the petrous ridges (Figs. 26-63 and 26-64).

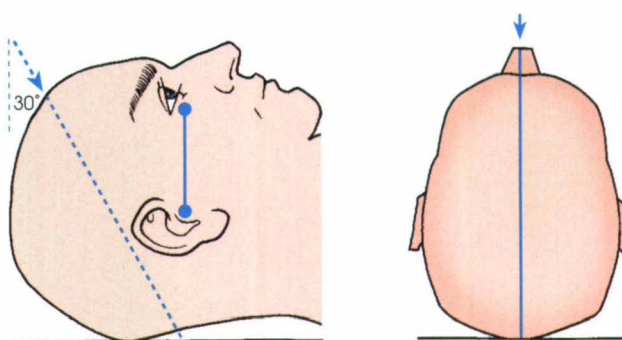


Fig. 26-63 AP axial projection for posterior circulation.



Fig. 26-64 Right vertebral artery injection demonstrates AP axial projection: showing vertebral basilar system.

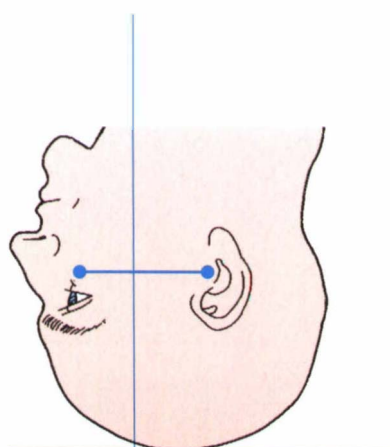


Fig. 26-65 SMV projection.

### SUBMENTOVERTICAL PROJECTION

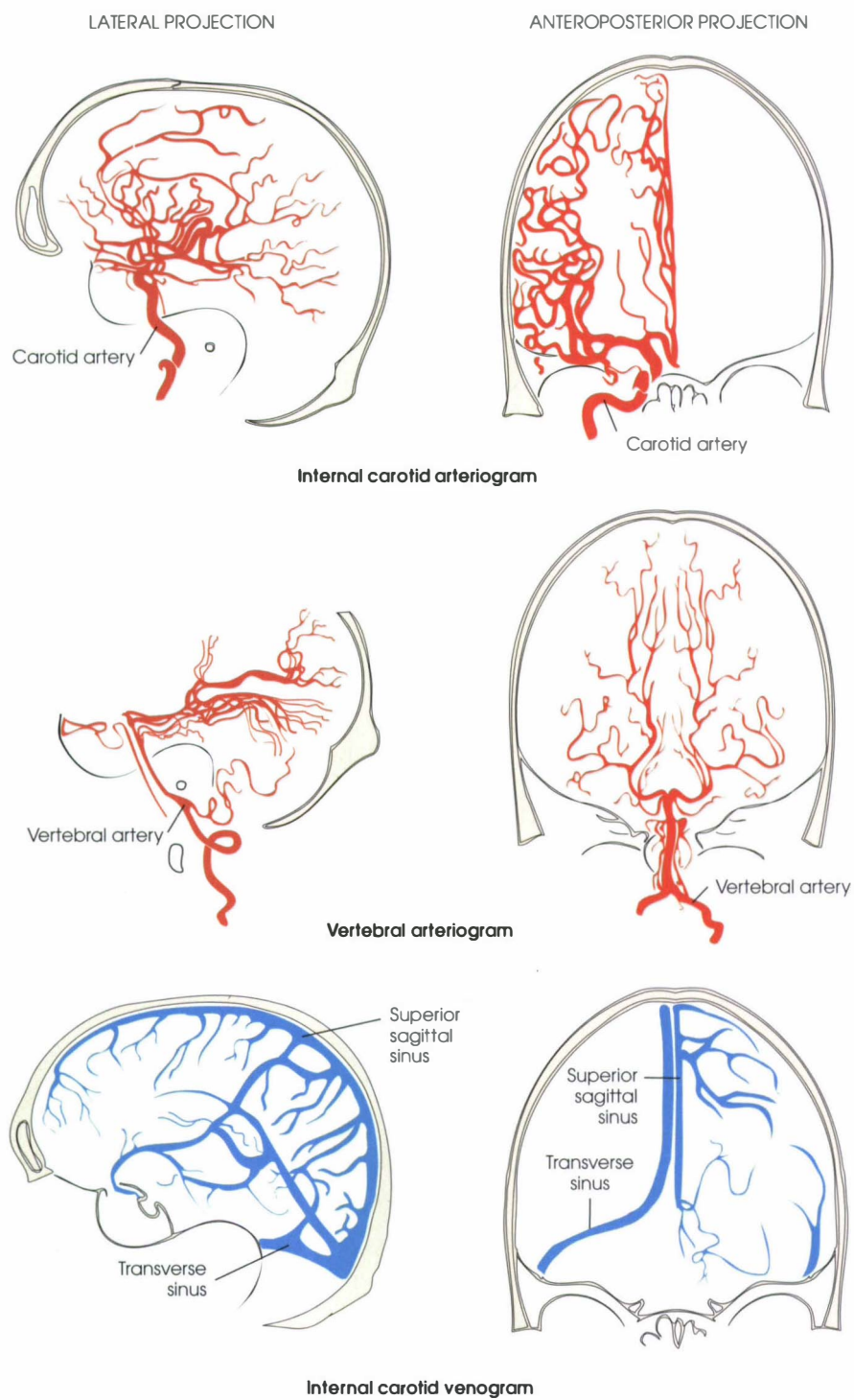
A modified submentovertical (SMV) projection is sometimes employed for the investigation of the posterior circulation. It is also used for the examination of the anterior circulation when a middle cranial fossa lesion is suspected.

The success of this projection depends on the patient's ability to hyperextend the neck and maintain this hyperextension for the time required for an imaging sequence (Figs. 26-65 and 26-66). This body position may not be possible for elderly patients with cervical degenerative arthritis. A chart detailing intracerebral circulation is provided in (Fig. 26-67).



Fig. 26-66 Right internal carotid artery injection demonstrates SMV projection. Note the multiple aneurysm clips.





**Fig. 26-67** Diagram of the intracranial circulation: Arterial and venous phase.

(From Bean BC: A chart of the intracerebral circulation, ed. 2, *Med Radiogr Photogr* 34:25, 1958; courtesy Dr. Berton C Bean and Eastman Kodak Co.)

*Interventional radiology* has a therapeutic rather than diagnostic purpose in that it intervenes in, or interferes with, the course of a disease process or other medical condition. Since the conception of this form of radiology in the early 1960s, its realm has become so vast and sophisticated that publishers of periodicals struggle to keep abreast of this rapidly advancing specialty.

Interventional radiology allows the angiographer to assume an important role in the management and treatment of disease in many patients. Interventional radiologic procedures reduce hospital stays in many patients and help some patients avoid surgery, with consequent reductions in medical costs.

Every interventional radiologic procedure must include two integral processes. The first is the interventional or medical side of the procedure, in which the highly skilled radiologist uses needles, catheters, and special medical devices (e.g., occluding coils, guide wires) to produce an improvement in the patient's status or condition. The second process involves the use of fluoroscopy and radiography to guide and document the progress of the steps taken during the first process. The CIT must receive special education in the angiographic and interventional suite. This skilled CIT has a very important role in assisting the angiographer in the interventional procedures.

The more frequently performed interventional procedures are described in the succeeding pages. Resources containing more detailed information are cited in the selected bibliography at the end of the chapter.

## Percutaneous Transluminal Angioplasty

*Percutaneous transluminal angioplasty (PTA)* is a therapeutic radiologic procedure designed to dilate or reopen stenotic or occluded areas within a vessel using a catheter introduced by the Seldinger technique. PTA using a coaxial catheter method was first described by Dotter and Judkins<sup>1</sup> in 1964. First a guide wire is passed through the narrowed area of a vessel. Then a smaller catheter is passed over the guide wire through the stenosis to begin the dilation process. Finally, a larger catheter is passed over the smaller catheter to cause further dilation, this method is referred to as the "Dotter Method" (Fig. 26-68). Although this method can achieve dilation of stenosis, it has the significant disadvantage of creating an arteriotomy as large as the dilating catheters.

<sup>1</sup>Dotter CT, Judkins MP: Transluminal treatment of arteriosclerotic obstruction: description of a new technique and preliminary report of its application, *Circulation* 30:654, 1964.

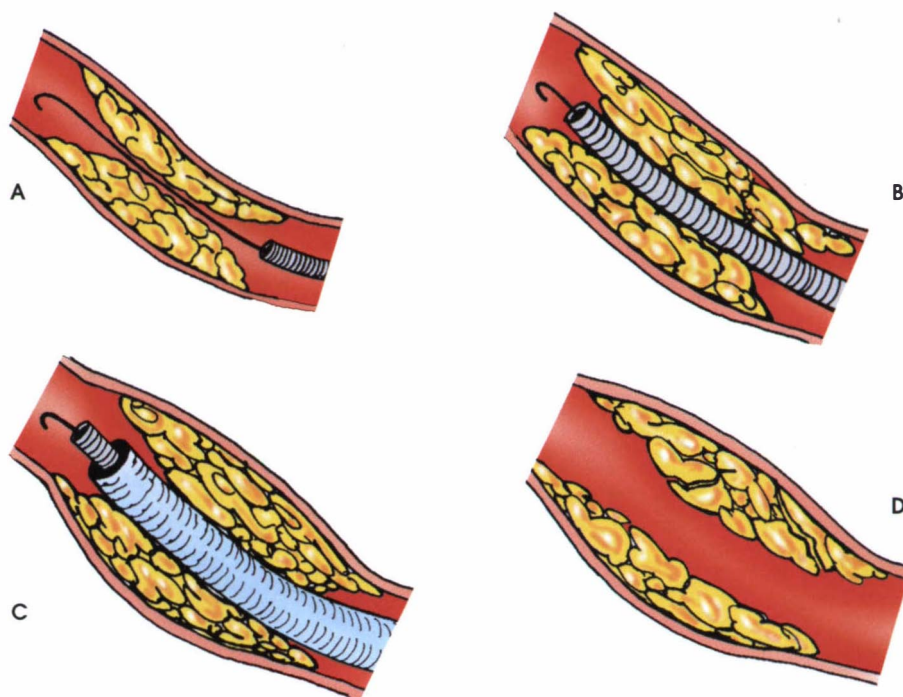
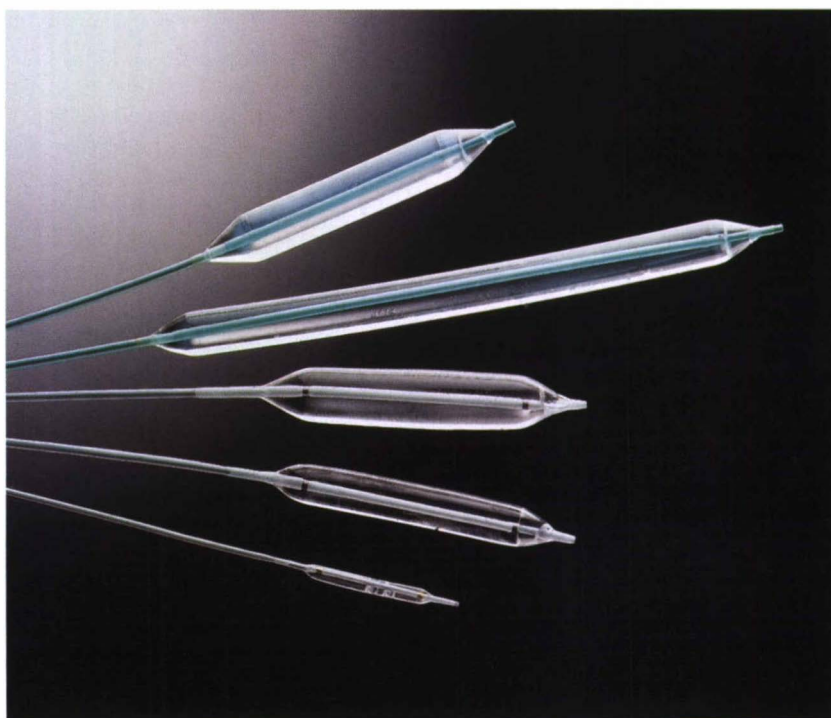


Fig. 26-68 Coaxial angioplasty of atherosclerotic stenosis, "Dotter Method": **A**, Guide wire advanced through stenosis. **B**, Small catheter advanced through stenosis. **C**, Large catheter advanced through stenosis. **D**, Post angioplasty stenotic area.

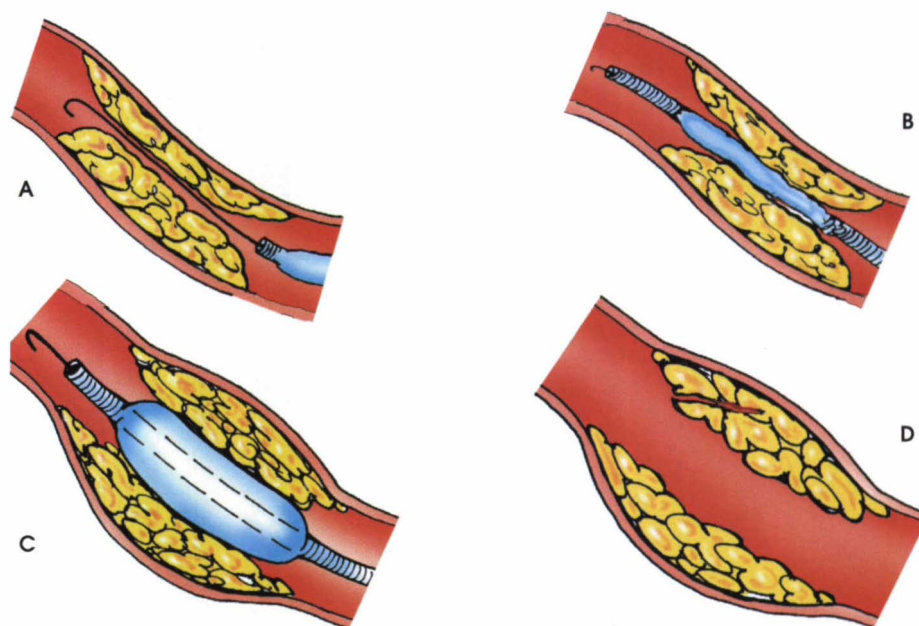
In 1974 Gruntzig and Hopff<sup>2</sup> introduced the double-lumen, balloon-tipped catheter. One lumen allows the passage of a guide wire and fluids through the catheter. The other lumen communicates with a balloon at the distal end of the catheter. When inflated, the balloon expands to a size much larger than the catheter. Double-lumen, angioplasty balloon catheters are available in sizes ranging from 3 to 9 Fr, with attached balloons varying in length and expanding to diameters of 2 to 20 mm or more (Fig. 26-69).

Fig. 26-70 illustrates the process of *balloon angioplasty*. The stenosis is initially identified on a previously obtained angiogram. The balloon diameter used for a procedure is often the measured diameter of the normal artery adjacent to the stenosis. The angioplasty procedure is often performed at the same time and through the same catheterization site as the initial diagnostic examination.



**Fig. 26-69** Balloon angioplasty catheters with varied diameters and lengths.  
(Courtesy Bard Radiology)

<sup>2</sup>Gruntzig A, Hopff H: Perkutane rekanalisation chronischer arterieller Verschlüsse mit einem neuen dilatationskatheter; modifikation der Dotter-Technik, *Deutsch Med Wochenschr* 99:2502, 1974.



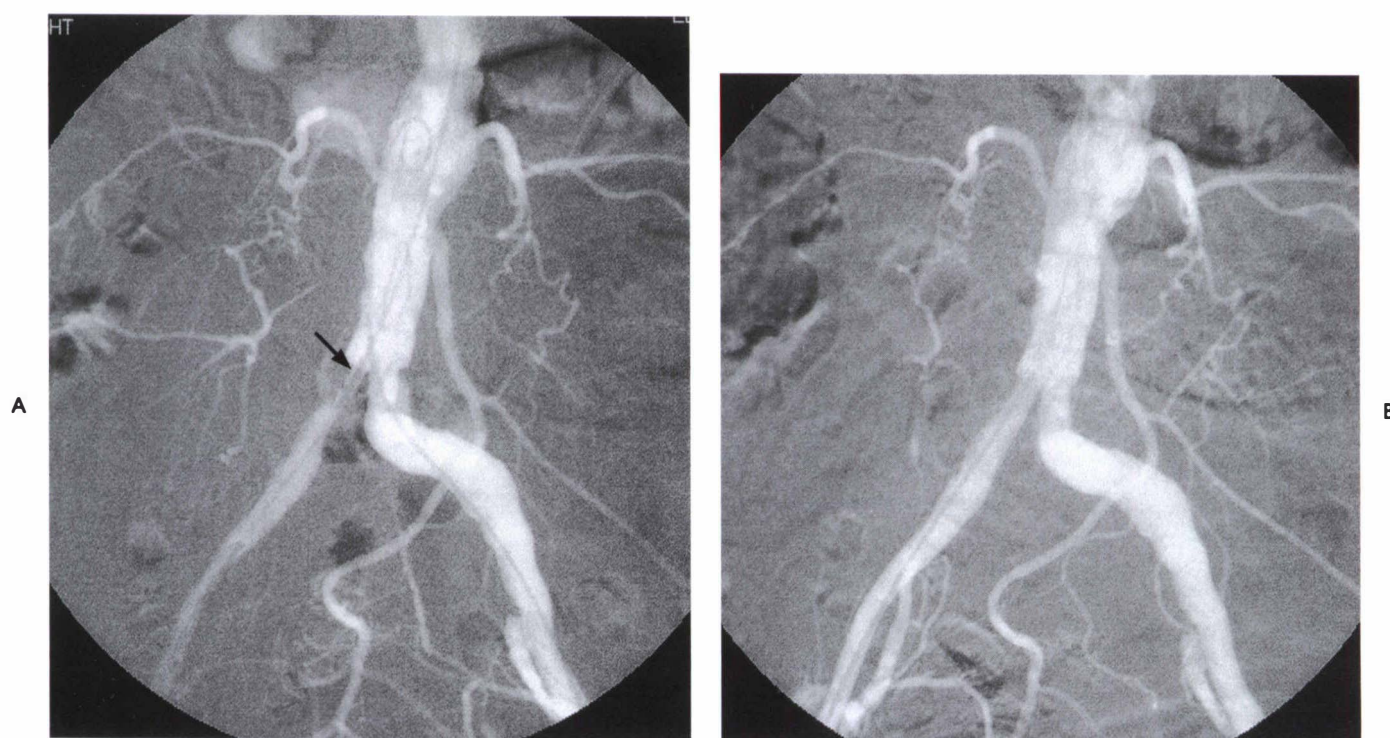
**Fig. 26-70** Balloon angioplasty of atherosclerotic stenosis. **A**, Guide wire advanced through stenosis. **B**, Balloon across stenosis. **C**, Balloon inflated. **D**, Postangioplasty stenotic area.



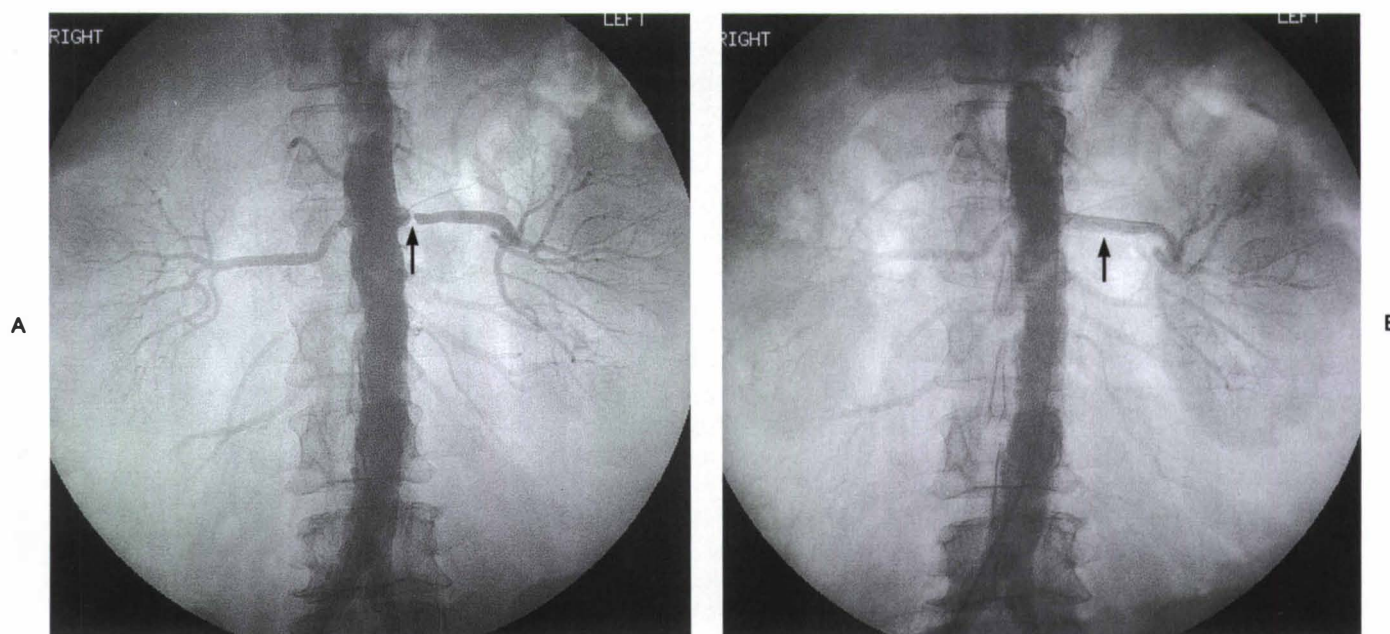
After the guide wire is positioned across the stenosis, the angiographic catheter is removed over the wire. The angioplasty balloon catheter is then introduced and directed through the stenosis over the guide wire. The balloon is usually inflated with a diluted contrast medium mixture for 15 to 45 seconds, depending on the degree of stenosis and the vessel being treated. The balloon is then deflated and repositioned or withdrawn from the lesion. Contrast medium can be injected through the angioplasty catheter for a repeat angiogram to determine whether or not the procedure was successful. The success of the angioplasty procedure may also be determined by comparing trans-catheter blood pressure measurements from a location distal and a location proximal to the lesion site. Nearly equal pressures indicate a reopened stenosis.

Transluminal angioplasty can be performed in virtually any vessel that can be reached percutaneously with a catheter (Figs. 26-71 and 26-72). In 1978, however, Molnar and Stockum<sup>1</sup> described the use of balloon angioplasty for dilation of strictures within the biliary system (Fig. 26-73). Balloon angioplasty is also conducted in venous structures, ureters, and the gastrointestinal tract.

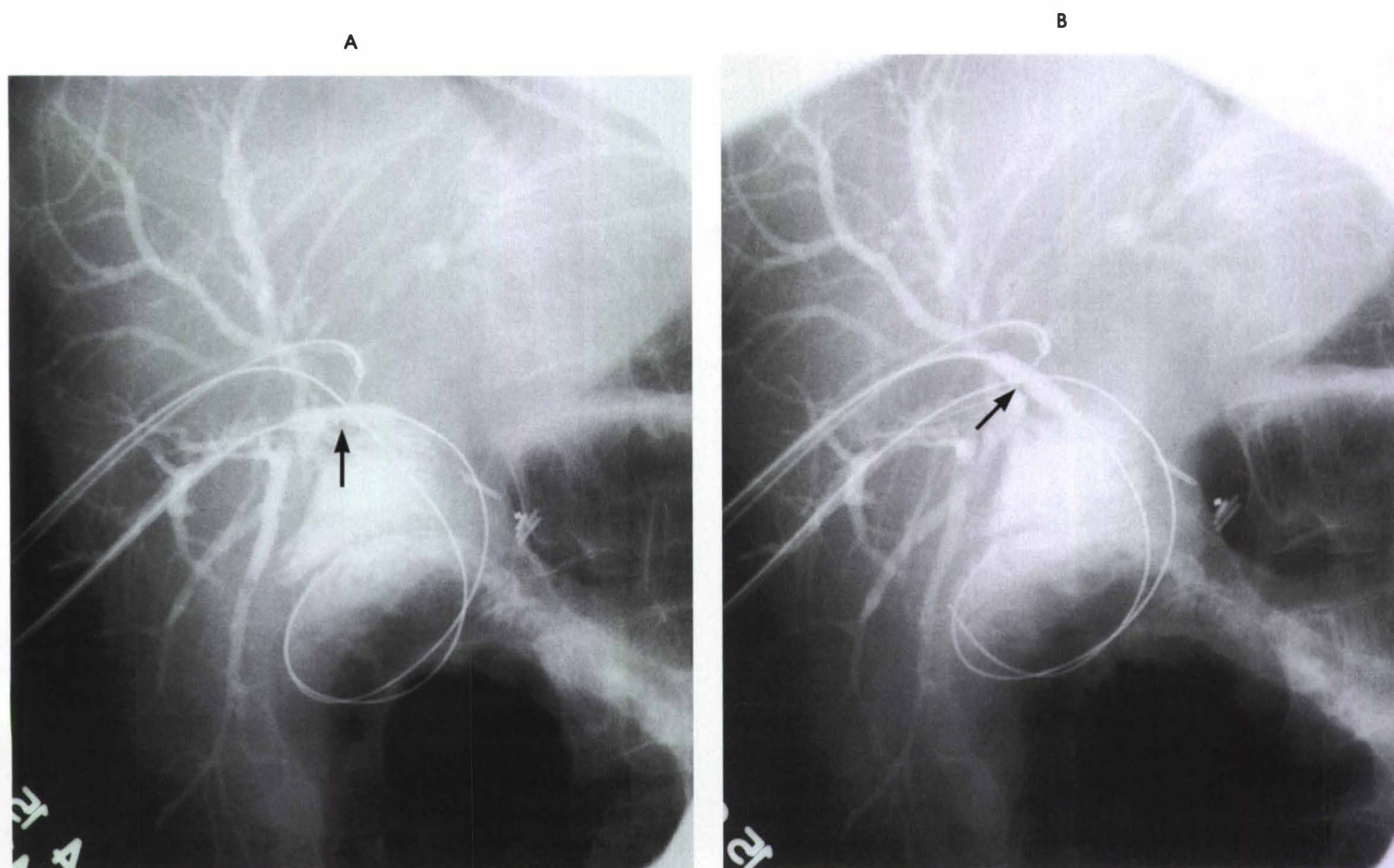
<sup>1</sup>Molnar W, Stockum AE: Transhepatic dilatation of choledochenterostomy strictures, *Radiology* 129: 59, 1978.



**Fig. 26-71** Digital subtracted images of the abdominal aortogram/bilateral iliac arteries demonstrates: **A**, High grade stenosis of the right common iliac artery, (arrow). **B**, Abdominal aortogram/bilateral iliac arteries, post-angioplasty, demonstrates widely patent iliac system.



**Fig. 26-72** Abdominal aortogram before and after angioplasty of the left renal artery. **A**, High grade stenosis of the left renal artery. (arrow). **B**, Post angioplasty and stent placement within the left renal artery (arrow).



**Fig. 26-73** Biliary duct injection with balloon angioplasty of two separate ducts: **A**, balloon wasting in an inferior duct (arrow). **B**, Balloon wasting in a superior duct (arrow).



Balloon angioplasty has been used successfully to manage various diseases that cause arterial narrowing. The most common form of arterial stenosis treated by transluminal angioplasty is caused by atherosclerosis. Dotter and Judkins<sup>1</sup> speculated that this atheromatous material was soft and inelastic and therefore could be compressed against the artery wall. The success of coaxial and balloon method angioplasty was initially attributed to enlargement of the arterial lumen because of compression of the atherosclerotic plaque. Later research showed, however, that the plaque does not compress. If plaque surrounds the inner diameter of the artery, the plaque cracks at its thinnest portion as the arterial lumen is expanded. Continued expansion cracks the arterial wall's inner layer, the *intima*, then stretches and tears the middle layer, the *media*, and finally stretches the outer layer, the *adventitia*. The arterial lumen is increased by permanently enlarging the artery's outer diameter. Restenosis, when it occurs, is usually caused by deposits of new plaque, not arterial wall collapse.

In addition to balloon angioplasty, other angioplasty technologies are used to treat atherosclerotic disease. Some of these technologies involve the use of lasers. In *laser-tipped angioplasty*, laser energy is directed through a special catheter and pulsed at the atheromatous mass to vaporize it. This process leaves a smooth, carbonized surface up to 5 mm in diameter, which is somewhat larger than the catheter tip. In *thermal angioplasty* a laser-heated probe is advanced through an atheroma to recanalize the vessel lumen. Compared with balloon angioplasty, thermal angioplasty creates a smoother surface so that less restenosis occurs at the lesion site. Sometimes a balloon angioplasty procedure follows lumen recanalization to further expand the vessel lumen.

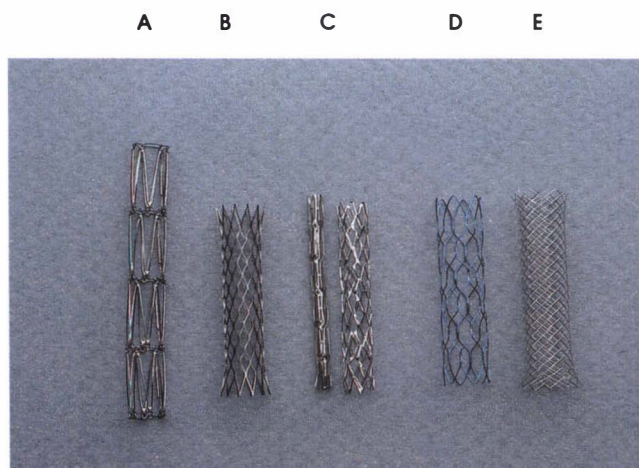
<sup>1</sup>Dotter CT, Judkins MP: Transluminal treatment of arteriosclerotic obstruction: description of a new technique and preliminary report of its application, *Circulation* 30:654, 1964.

*Percutaneous atherectomy* is an angioplasty technology that removes an atheroma by cutting it. Atherectomy catheter systems are either rotational or directional. A *rotational* catheter system has a blunt cam at the distal tip of the catheter that rotates at speeds up to 100,000 rpm. A fluid mixture is infused through the catheter as the cam rotates, creating a radial fluid spray. Together the rotating cam and fluid spray cut and recirculate atherosclerotic material until it is micropulverized, whereas normal tissue is spared. A balloon angioplasty procedure frequently follows lumen restoration by this method.

A *directional* atherectomy catheter system has, at its distal end, a cylindrically shaped chamber called the *housing* with an opening along one side called the *housing window*. Opposite the housing window is a balloon that, when inflated, presses the atheromatous mass into the window. A round, rotating cutter is then advanced through the housing to cut the atheroma, which is collected in the distal housing chamber. The balloon is then deflated, and the housing window is rotated 90 degrees in the vessel. The procedure is repeated until the atheroma has been removed circumferentially from the vessel lumen.

A final possibility for percutaneous treatment of vessel stenoses is the placement of vascular stents. A vascular *stent* is a wire or plastic cylinder that is introduced through a catheter system and positioned across a stenosis to keep the narrowed area spread apart. These devices permanently remain in the vessel (Fig. 26-74).

The success of PTA in the management of atherosclerosis has made it a significant alternative to surgical procedures in the treatment of this disease. PTA is not indicated in all cases, however. Long segments of occlusion, for example, may be best treated by surgery. PTA has a lower risk than surgery but is not totally without risk. Generally patients must be able to tolerate the surgical procedure that may be required to repair vessel damage that can be caused by PTA. Unsuccessful transluminal angioplasty procedures rarely prevent or complicate necessary subsequent surgery. In selected cases the procedure is effective and almost painless and can be repeated as often as necessary with no apparent increase in risk to the patient. The recovery time is often no longer than the time required to stabilize the arteriotomy site, usually a matter of hours, and general anesthesia is normally not required. Therefore the hospital stay and the cost to the patient are reduced.



**Fig. 26-74** Intravascular stents: **A**, Gianturco Rosch biliary Zstent. **B**, Memotherm. **C**, Palmaz; unexpanded and expanded. **D**, Symphony. **E**, Wallstent.



Although most PTA procedures are conducted in the radiology angiographic suite, angioplasty involving the arteries of the heart is generally performed in a more specialized laboratory. *Percutaneous transluminal coronary angioplasty (PTCA)* takes place in the cardiac catheterization laboratory because of the possibility of potentially serious cardiac complications. Further information on PTCA is provided later in this chapter.

### BOX 26-1

#### Lesions amenable to embolization

- a. Aneurysm
- b. Pseudoaneurysm
- c. Hemorrhage
- d. Neoplasms
  - Malignant
  - Benign
- e. Arteriovenous malformations (AVM)
- f. Arteriovenous fistula (AVF)
- g. Infertility (varicocele)
- h. Impotence due to venous leakage
- i. Redistribution of blood flow

## Transcatheter Embolization

Transcatheter embolization was first described by Brooks<sup>1</sup> in 1930. He described vessel occlusion for closure of arteriovenous fistula. Transcatheter embolization involves the therapeutic introduction of various substances to occlude or drastically reduce blood flow within a vessel (Box 26-1). The three main purposes for embolization are (1) to stop active bleeding sites, (2) to control blood flow to diseased or malformed vessels (e.g., tumors or AVMs), and (3) to stop or reduce blood flow to a particular area of the body before surgery.

<sup>1</sup>Brooks B: The treatment of traumatic arteriovenous fistula. *South Med J* 23:100, 1930.

Brooks B: Discussion. In Nolan L, Taylor AS: Pulsating exophthalmos. *Trans South Surg Ass* 43:176, 1931.

The patient's condition and the situation must be considered when choosing an embolic agent. The Interventionalist usually identifies the appropriate agent to be used. Embolic agents must be administered with care to ensure that they flow to the predetermined vessel or target. Embolization is a permanent treatment, the effects on the lesion are irreversible. Many embolic agents are available (Box 26-2), and the choice of agent depends on whether the occlusion is to be temporary or permanent (Table 26-1).

Temporary agents such as Gelfoam\* or avitene may be utilized as a means to reduce the pressure head of blood to a specific site. These temporary agents will reduce flow into a bleeding site so that hemostasis may be achieved. Temporary agents can also be used to protect normal vessels from being inadvertently embolized.

\*Gelfoam is the trademark for a sterile, absorbable, water-insoluble gelatin-base sponge.

### BOX 26-2

#### Particulate agents

- Polyvinyl alcohol (PVA)
- Embosphere
- Avitene
- Gelfoam
- Suture material

#### Metal coils

- Gianturco coils
- Metal coils
- Detachable coils

#### Liquid agents (occluding, sclerosing)

- Ethanol
- Thrombin
- Boiling contrast
- Hypertonic glucose
- Sodium tetradecyl sulfate
- Ethibloc
- EVAL
- Onyx

#### Detachable balloons

- Latex - Debrun
- Silicone - Heishima

#### Liquid adhesives

- N-butyl 2-cyanoacrylate

#### Autologous material

TABLE 26-1

#### Particulate agent sizes

• Gelfoam Powder	40-60 microns
• Gelfoam Sponges	Pledgets-torpedoes
• Avitene	100-150 microns
• Polyvinyl Alcohol (PVA)	100-1200 microns
• Embosphere	100-1200 microns

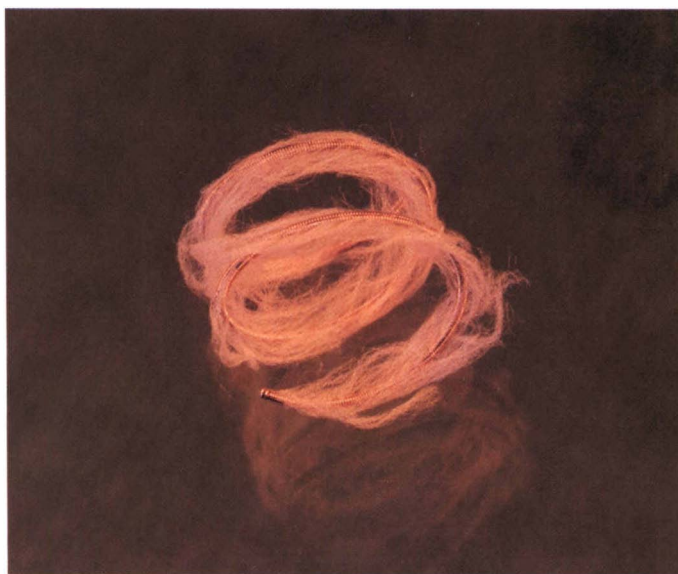


Fig. 26-75 Fibred Gianturco stainless-steel occluding coil (magnified).

*Vasoconstricting* drugs can be used to temporarily reduce blood flow. Vasoconstrictors such as vasopressin (Pitressin) drastically constrict vessels, resulting in hemostasis.

When permanent occlusion is desired, as in trauma to the pelvis that causes hemorrhage or when vascular tumors are supplied by large vessels, the Gianturco stainless-steel coil may be utilized. This coil (Fig. 26-75), which functions to produce thrombogenesis, is simply a looped segment of guide wire with Dacron fibers attached to it. The coil is initially straight and is easily introduced into a catheter that has been placed into the desired vessel. The coil is then pushed out of the catheter tip with a guide wire. The coil assumes its looping shape immediately as it enters the bloodstream. It is important that the catheter tip be specifically placed in the vessel so that the coil springs precisely into the desired area. Numerous coils can be placed as needed to occlude the vessel.



Fig. 26-76 Hypervascular uterine fibroid: **A**, Bilateral uterine artery injections, utilizing coaxial micro catheters, demonstrates hypervascular uterine fibroid. **B**, Bilateral iliac artery injections, post embolization, demonstrates total occlusion of both uterine arteries (arrows).



Fig. 26-76 represents an example of a hypervascular uterine fibroid that was causing significant symptoms to the patient. This uterine fibroid was successfully embolized with total occlusion of the lesion.

Transcatheter embolization has also been used in the cerebral vasculature of the brain. Vascular lesions within the cerebral vasculature, such as aneurysms, AVMs, and tumors, can be managed using multiple embolic agents, PVA or tissue adhesive. Very small catheters (2 or 3 Fr) are passed through a larger catheter, coaxial system that is positioned in the cerebral vessels. The smaller catheter is then manipulated into the appropriate cerebral vessel, and lesions such as an aneurysm and the embolic material is delivered through it, until the appropriate embolization is achieved (Fig. 26-77).

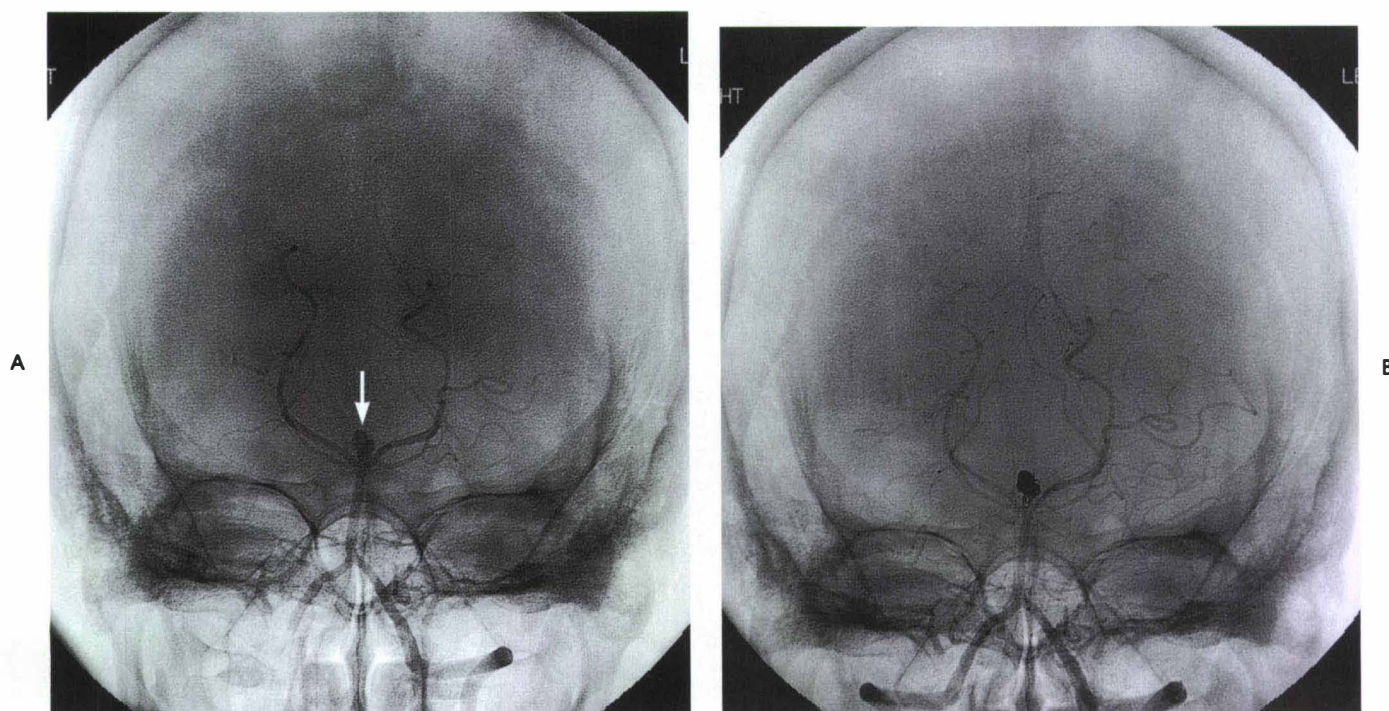
## Percutaneous Nephrostomy Tube Placement and Related Procedures

*Nephrostomy* tube drainage is indicated in the patient who has some type of ureteral or bladder blockage that causes *hydronephrosis*. If urine is not eliminated from the kidney, renal failure with necrosis to the kidney may occur, as well as sepsis.

A nephrostomy tube is a catheter that has multiple side holes at the distal end through which urine can enter. The urine drains into a bag connected to the proximal end of the drainage catheter outside the patient's body. These catheters range in size from 8 to 12 Fr and are usually about 12 inches (30 cm) in length. Nephrostomy tubes are also placed in patients with kidney stones to facilitate subsequent passage of ultrasonic lithotripsy catheters.

The renal pelvis must be opacified to provide a target for percutaneous nephrostomy tube placement. Percutaneous nephrogram may be performed to accomplish this. For this procedure the patient is positioned prone or in an anterior oblique position on the tabletop. The patient's back and posterolateral aspect of the affected side are prepared and surgically draped. Following the administration of a local anesthetic, a 7-inch (17-cm) thin-wall cannula needle is passed through the back under fluoroscopic control and the cannula is removed. The needle is examined for drainage of urine. When urine returns through the needle, contrast medium is injected to opacify the renal pelvis.

A posterior calyx of the opacified renal pelvis is often selected as the target for the nephrostomy tube placement. After a local anesthetic is administered, a 7-inch (17-cm) cannula needle is inserted through the posterolateral aspect of the back and directed toward the renal pelvis. A fluoroscopic C-arm offers a distinct advantage for this process. The C-arm can be obliqued to match the angle between the needle insertion site and the target. The needle can then be advanced directly toward the target visualized on the fluoroscopic monitor. The C-arm is then angled obliquely 90 degrees to see if the needle tip has reached the renal pelvis or calyx.

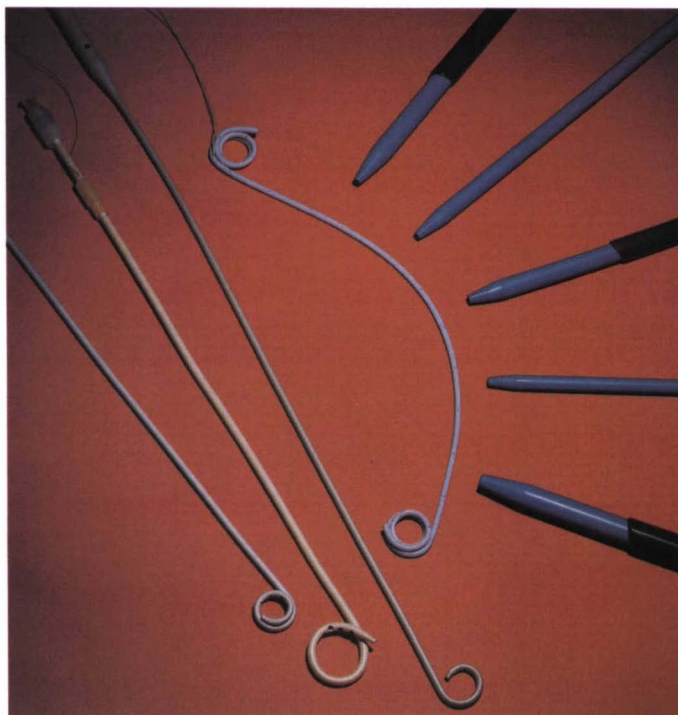


**Fig. 26-77** Left vertebral artery injection demonstrates: **A**, Basilar tip aneurysm (arrow). **B**, Left vertebral artery injection post embolization with the use of Guglielmi detachable coils, GDC.





**Fig. 26-78** Left nephrostogram through Coop Loop drainage tube, note high-grade stenosis of the distal ureter causing hydronephrosis.



**Fig. 26-79** Nephrostomy tubes (*left*) ureteral stent (*center*), and dilators.

(Courtesy Cook, Inc., Bloomington, Ind.)

When the needle tip has entered the desired target, a guide wire is passed through the needle into the renal pelvis and is then maneuvered into the proximal ureter for additional support. The needle is then removed, the tract is dilated, and the drainage catheter is passed over the guide wire and into the renal pelvis. The pigtail end of the catheter must be placed well within the renal pelvis and not outside the kidney itself or in the proximal ureter (Figs. 26-78 and 26-79). The catheter's position is maintained by attaching it to a fixation disk or other device that is then sutured or taped to the body wall. A dressing is applied over the entry site. Either the fixation device or the dressing must prevent the catheter from becoming kinked, which would prevent the drainage of urine through the catheter. Periodic antegrade nephrograms may be performed by injecting the drainage catheter to evaluate anatomy and catheter function.

Nephrostomy tubes may be placed for temporary or permanent external drainage of urine. Nephrostomy tubes that are left in place for a long period of time need to be exchanged periodically for new ones. A guide wire is inserted through the existing catheter, and the catheter is removed, leaving the guide wire in place. A new nephrostomy tube is then passed over the guide wire and positioned in the renal pelvis. Nephrostomy tubes can be permanently removed by simply pulling them out. The tract from the body wall to the renal pelvis usually closes in a day or so without complication.

In addition to nephrostomy tube placement, other *uroradiologic* procedures are performed in the angiographic and interventional suite. *Percutaneous nephrolithotomy* is an alternative to surgical removal of relatively small kidney stones. Large stones may require surgery or ultrasonic lithotripsy for removal. The percutaneous nephrolithotomy procedure begins with a nephrostomy tube placement. After a wire is passed into the renal pelvis and ureter, a large tract is formed using dilators or an angioplasty balloon catheter. Then a sheath large enough to facilitate removal of the stone is placed between the renal pelvis and the body wall. A stone basket or other retrieval catheter is introduced through the tract and manipulated to grasp the stone (Figs. 26-80 and 26-81). The stone is removed by withdrawing the retrieval catheter as it grasps the stone. The sheath is then withdrawn, and a nephrostomy tube is placed in the renal pelvis to drain urine and any blood resulting from trauma in the procedure. The nephrostomy tube is eventually removed.

Angioplasty of stenoses in the ureteral system, renal cyst puncture with drainage, and percutaneous antegrade ureteral stent placement are additional procedures. A ureteral stent is a double-ended pigtail catheter that is passed into the ureter and remains inside the body, with one end placed into the renal pelvis and the other into the bladder (Fig. 26-82). This catheter is used when a constriction of the ureter or ureterovesicular junction is blocking the drainage of urine from the renal pelvis. The multiple side holes at both pigtail ends allow urine to drain into one end of the stent and exit the other end. The stent provides an internal passageway for urine across the area of blockage. A nephrostomy tube is initially placed to provide access to the renal pelvis and to allow a tract to form in the body. At a later time, a guide wire is passed through the nephrostomy tube and down the ureter into the bladder. The nephrostomy tube is removed, and the stent is inserted over the guide wire using a pusher. The nephrostomy tube is replaced to provide external drainage until it is known that the stent is providing internal drainage. The stent can usually be removed through the urethra by a cystoscopic procedure.

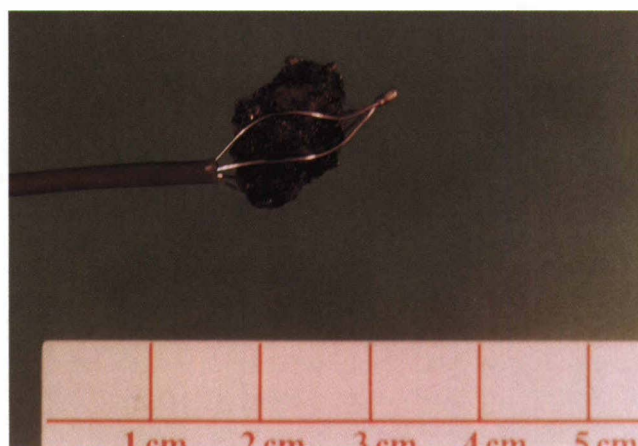


Fig. 26-80 Retrieval catheter and basket with large renal stone.  
(Courtesy John R. Croyle.)

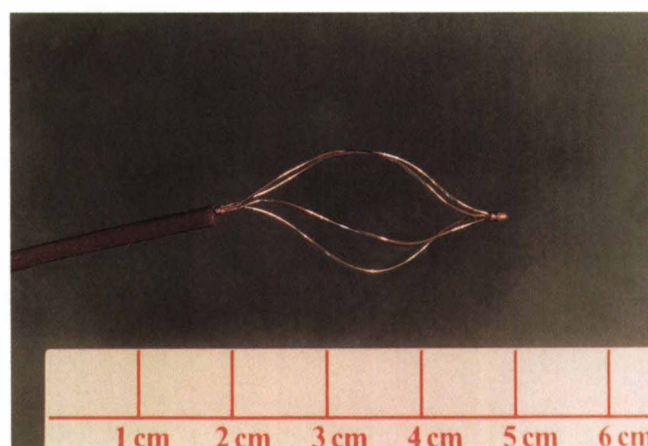


Fig. 26-81 Retrieval catheter with stone basket extended.  
(Courtesy John R. Croyle.)

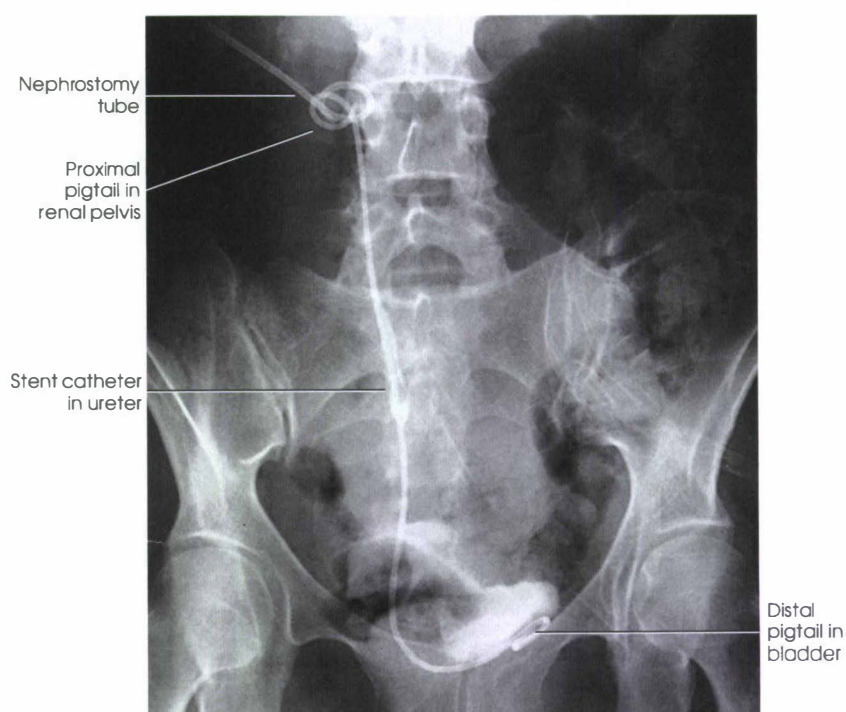


Fig. 26-82 Post placement image of left ureteral stent and left nephrostomy.



## Inferior Vena Cava Filter Placement

The idea of interrupting the pathway of an embolus is not a new one. Surgical interruption of the common femoral vein was first described in 1784, and surgical interruption of the inferior vena cava was described in 1868. These procedures and the partial surgical interruption procedures that evolved from them had a high rate of complications, not only due to the surgical process but also to inadequate venous drainage from the lower limbs. Catheterization technology led to the development of detachable balloons for occluding the inferior vena cava, but that procedure also resulted in complications because of inadequate venous flow from the lower limbs.

Pulmonary angiography primarily evaluates embolic disease of the lungs. A pulmonary embolus is a blood clot, which forms as a thrombus, and usually develops in the deep veins of the leg (Fig. 26-83). When such a thrombus becomes dislodged and migrates, it is called an embolus. An embolus originating in the leg may migrate through the inferior vena cava and right side of the heart and finally lodge in the pulmonary arteries. A filter can be percutaneously placed in the inferior vena cava to trap such an embolus.

Lower limb vein thrombosis is not necessarily an indication for inferior vena cava filter placement. Normally blood-thinning medications are administered to treat deep vein thrombosis. When anticoagulant therapy is contraindicated because of bleeding or the risk of hemorrhage, filter placement may be indicated. Filter placement itself has associated risks, including thrombosis of the vein through which the filter is introduced and thrombosis of the vena cava. However, these risks normally are not life threatening. It is important to note that inferior vena cava filter placement is not a treatment for deep vein thrombosis of the leg but a therapy intended to reduce the chance of pulmonary embolism.

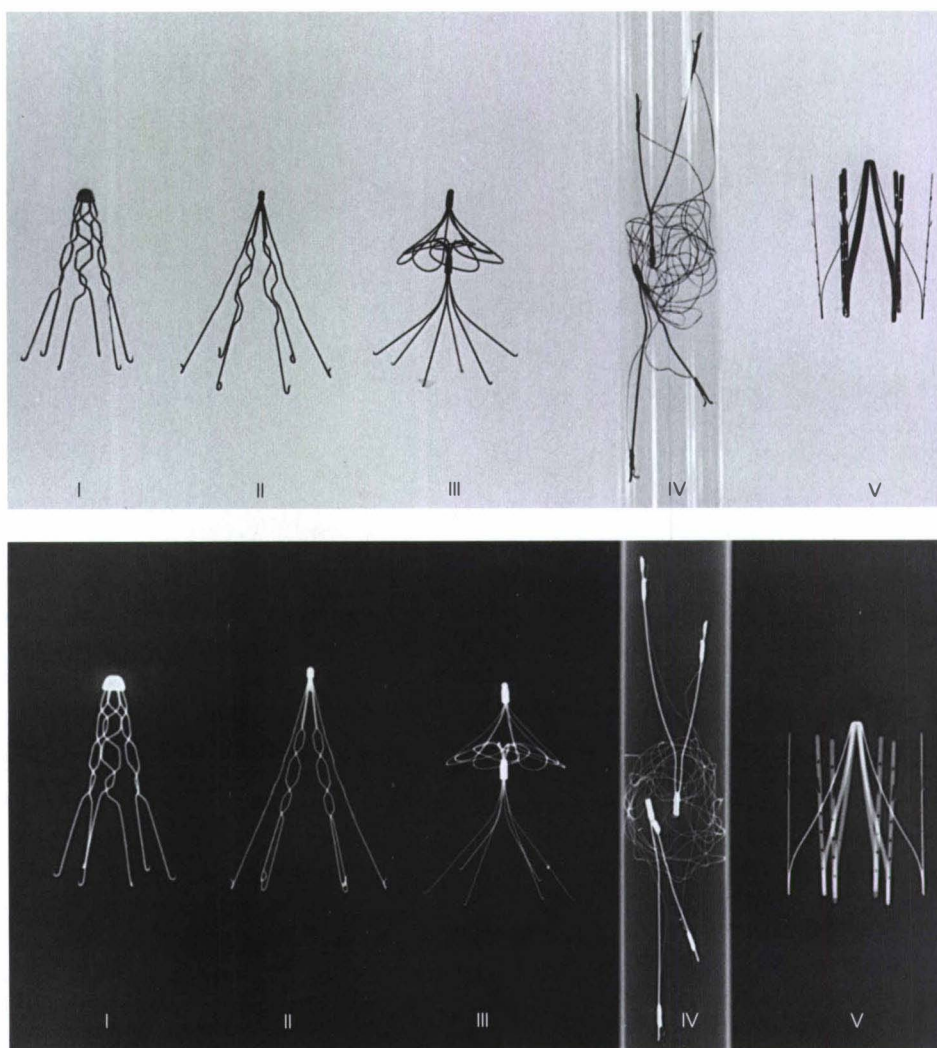


Fig. 26-83 Lower limb venogram.

The first true filter designed to trap emboli while maintaining vena cava patency was introduced in 1967 by Mobin-Uddin. It consisted of six metal struts joined at one end to form a conical shape that was covered by a perforated plastic canopy. The plastic canopy proved to be too occlusive, and this is why the Mobin-Uddin filter is no longer in use. Because of this filter's striking resemblance to an open umbrella, vena cava filters of all types were for many years referred to as "umbrella filters."

Inferior vena cava filters are available in a variety of shapes. All of these filters are initially compact inside an introducer catheter device and assume their functional shape as they are released (Fig. 26-84). The introducers are passed through sheaths ranging in size from 6 to 15 Fr.

Most filters are designed as a conical shape to trap clots in its central lumen. They are also designed to be placed in vena cava's ranging up to 20 to 30 mm in diameter. Each filter has its own mechanism of clot trapping. Although Fig. 26-84 demonstrates the most currently available permanent IVC filters, there are on-going trials of temporary filters. These filters would be employed as a temporary means to prevent new pulmonary embolus. While patients are in an acute high-risk state, these temporary filters may help in the prevention of pulmonary embolus. No matter if the filter is permanent or temporary, the purpose of preventing and trapping new onset of pulmonary embolus. It does not treat the preexisting clots though.



**Fig. 26-84** Vena cava filters: I, Kimray-Greenfield; II, Titanium Greenfield; III, Simon Nitinol; IV, Gianturco-Roehm Bird's Nest; V, Vena Tech. **A**, Photographic image. **B**, Radiographic image.



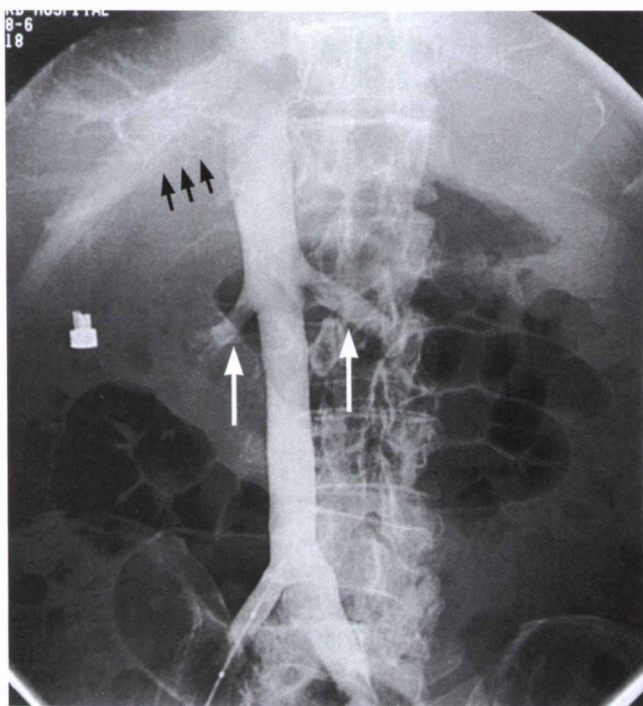


Fig. 26-85 Inferior vena cavogram note reflux into the renal veins (*large arrows*) and hepatic veins (*small arrows*).



Fig. 26-86 Post placement image showing Greenfield filter in place (*arrow*).

Several filters are designed for temporary placement. They have hooks on the top and the bottom that allows them to be grasped by a catheter snare device and removed percutaneously. Another temporary filter remains attached to its introducer catheter, which is used to retrieve it. Some temporary filters must be removed within approximately 10 days or they become permanently attached to the vena cava endothelium. Various filter designs are in use in countries other than the United States. Inferior vena cava filter development continues, and new designs will certainly become available.

The filters are percutaneously inserted through a femoral, jugular, or antecubital vein, usually for placement in the inferior vena cava just inferior to the renal veins. Placement inferior to the renal veins is important to prevent renal vein thrombosis, which can occur if the vena cava is occluded superior to the level of the renal veins by a large thrombus in a filter. An inferior vena cavogram is performed using the Seldinger technique, usually from the femoral vein approach. The inferior vena cavogram defines the anatomy, including the level of the renal veins, determines the diameter of the vena cava, and rules out the presence of a thrombus (Fig. 26-85). Filter insertion from the jugular or antecubital approach may be indicated if a thrombus is present in the inferior vena cava.

The diameter of the vena cava may influence the choice of filter, because each filter has a maximum diameter. The filter insertion site is dilated to accommodate the filter introducer. The filter remains sheathed until it reaches the desired level and is released from its introducer by the angiographer. The introducing system is then removed, and external compression is applied to the venotomy site until hemostasis is achieved. A post placement image is obtained to document the location of the filter (Fig. 26-86).

## Transjugular Intrahepatic Portosystemic Shunt

The *portal circulation* consists of blood from the digestive organs, which drains into the liver. The portal system consists of the splenic vein, the superior mesenteric vein, and the inferior mesenteric vein. The blood passes through the liver tissue and is returned to the inferior vena cava via the hepatic veins. Disease processes can increase the resistance of blood flow through the liver, elevating the portal circulation's blood pressure—a condition known as *portal hypertension*. It may cause the blood to flow through collateral veins. Venous *varicies* are the result and can be life-threatening if they bleed. The creation of a portosystemic shunt can decrease portal hypertension and the associated variceal bleeding by allowing the portal venous circulation to bypass its normal course through the liver. The percutaneous intervention for creating an artificial low-pressure pathway between the portal and hepatic veins is called a *transjugular intrahepatic portosystemic shunt (TIPS)*.

Portography and hepatic venography are usually performed before a TIPS procedure to delineate anatomy and confirm *patency* of these vessels. Ultrasonography may be used for this purpose. Transcatheter blood pressure measurements may also confirm the existence of a pressure gradient between the portal and hepatic veins.

The most common approach for a TIPS procedure is from a right internal jugular venous puncture site to the middle or right hepatic vein. A hepatic venogram may be obtained using contrast material and/or CO<sub>2</sub>. A special long needle is passed into the hepatic vein and advanced through the liver tissue into the portal vein. The needle is exchanged for an angioplasty balloon catheter, and the tract through the liver tissue is dilated. An angiographic catheter may be passed through the tract and advanced into the splenic vein for a splenoportal venogram. An intravascular stent is positioned across the tract to maintain its patency (Fig. 26-87). The tract and stent may be further enlarged with an angioplasty balloon catheter until the desired reduction in pressure gradient between the portal and hepatic veins is achieved. The sheath is then removed from the internal jugular vein, and external pressure is applied until hemostasis at the venotomy occurs.

## Other Procedures

When an angiogram demonstrates thrombosis, the procedure may be continued for thrombolytic therapy. Blood clot-dissolving medications can be infused through an angiographic catheter positioned against the thrombus. Special infusion catheters that have side holes may be manipulated directly into the clot. Periodic repeat *angiograms* evaluate the progress of *lysis* (dissolution). The catheter may have to be advanced under fluoroscopic control to keep it against or in the clot as lysis progresses.

Catheters can also be used to percutaneously remove foreign bodies, such as catheter fragments or broken guidewires, from the vasculature. A variety of snares can be used for this purpose. A snare catheter introduced using the Seldinger technique is manipulated under fluoroscopic control to grasp the foreign body. Then the snare and foreign body are withdrawn as a unit.

Interventional radiologic procedures performed in the biliary system include biliary drainage and biliary stone removal (see Chapter 16).

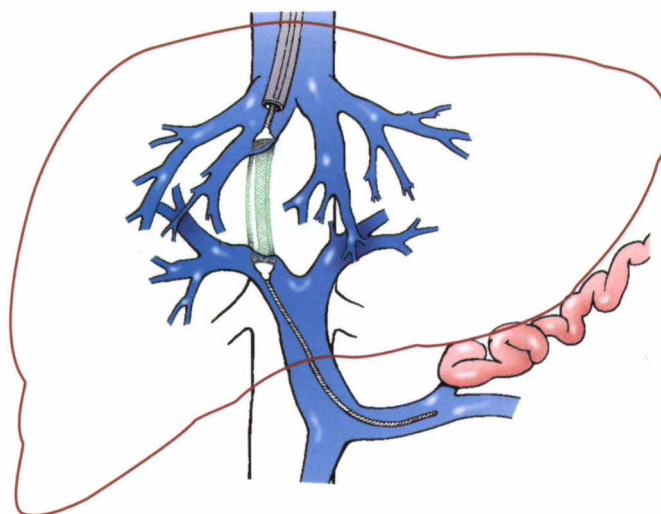


Fig. 26-87 Intravascular stent placement in a TIPS procedure.





**Fig. 26-88** The Cardiovascular and Interventional Technologist plays an active role on the Interventional team. Assisting the interventionalist (*left*) or by circulating within the angi-suite (*right*).

## Interventional Radiology: Present and Future

Interventional procedures bring therapeutic capabilities into the hands of the interventional radiologist. Procedures are done for diagnosis and treatment on multiple lesions. The treatment procedures can be performed at the same time as the diagnostic procedure. New equipment is continually becoming available to improve techniques and broaden the scope of percutaneous intervention. Although use of the catheter for angiographic diagnosis may wane, its ability to provide therapy percutaneously ensures a future for angiography. These procedures are highly technical and a team approach is most important. The cardiovascular and interventional technologist plays an active role on this interventional team<sup>1</sup> (Fig. 26-88). Along with interventional technologist, the other members of the team would be the nurse, support personnel, as well as the Interventionalist. Although these procedures are performed in an angiographic suite, this subspecialty of Radiology can be considered less invasive surgery. The field can also be called Surgical Angiography and Surgical Neuroangiography. This field of Interventional Radiology has a bright future with the development of newer and more sophisticated equipment.

## Definitions and Indications

*Lymphography* is a general term applied to radiologic examinations of the lymph vessels and nodes after they have been opacified by an injected oil based contrast medium (Figs. 26-89 and 26-90). The study of the lymph vessels, which may be called lymphangiography, is carried out within the first hour after injection of the contrast material. The study of the lymph nodes, which may be called lymphadenography, is performed 24 hours after injection of the contrast medium. The lymph vessels empty the contrast agent within a few hours. The nodes normally retain the contrast substance for 3 to 4 weeks. Abnormal nodes may retain the medium for several months, so delayed lymphadenograms may be made, as indicated, without further injection.

Lymphography is seldom performed in current practice because of the superior imaging capabilities of newer modalities. At present its primary purpose is to assess the clinical extent of lymphomas. Lymphography may also be indicated in patients who demonstrate clinical evidence of obstruction or other impairment of the lymphatic system. A more detailed description of lymphography is provided in previous editions of this text.

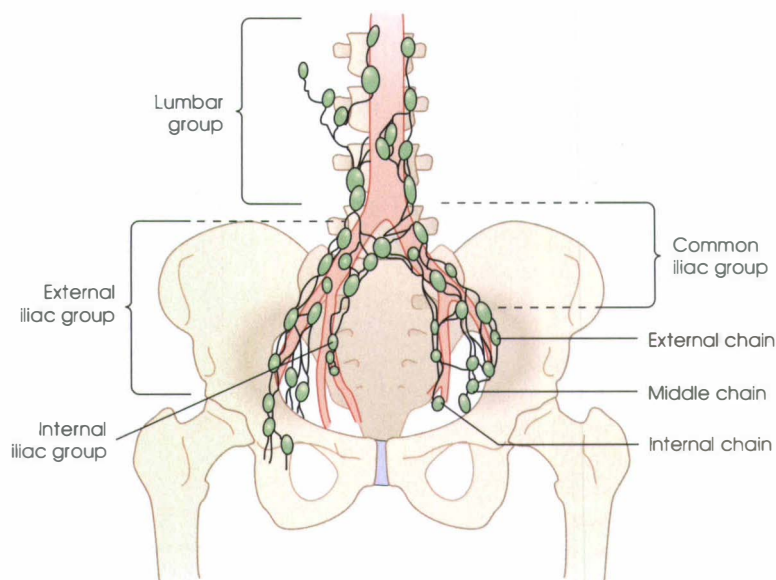


Fig. 26-89 Iliopelvic-aortic lymphatic system: anterior projection.



Fig. 26-90 AP projection of ilio pelvic-abdomino-aortic lymph nodes.



## Procedures

### INJECTION

Injections for lymphography are limited to easily accessible sites such as those of the hands and feet (Table 26-2). (Lymphatics of the feet are most commonly used.) For opacification of the lymphatic vessels and nodes, the vessels must be isolated and cannulated. Ordinarily the peripheral lymphatic vessels cannot be easily identified because of their small size and lack of color. For identification of the lymphatic vessels on the dorsum of the feet and hands, a blue dye that is selectively absorbed by the lymphatics is injected subcutaneously into the first and second interdigital web spaces about 15 minutes before the examination. (After patent blue violet is injected, the patient's urine and skin are tinted blue. This condition disappears within a few hours.)

A longitudinal incision is made on the dorsum of each hand or foot to locate the dye-filled lymphatic vessels. A 27- or 30-gauge needle is used to cannulate the isolated vessels. Iodinated oily contrast media is then slowly injected into the vessels over a 30-minute period. (As in any procedure involving the injection of foreign materials, untoward reactions must be anticipated. The patient must be observed closely, and appropriate medications and resuscitation equipment must be nearby.) Confirmation that the injection is intra-lymphatic is usually obtained fluoroscopically. After the injection, the needles are removed and the wounds sutured.

Injection of the feet provides visualization of the lymphatic structures of the lower limb (Fig. 26-91), groin, iliopelvic-abdomino-aortic region, and thoracic duct. Injection of the lymphatics of the hands provides visualization of the upper limb (Fig. 26-92) and the axillary, infraclavicular, and supraclavicular regions.

### IMAGING

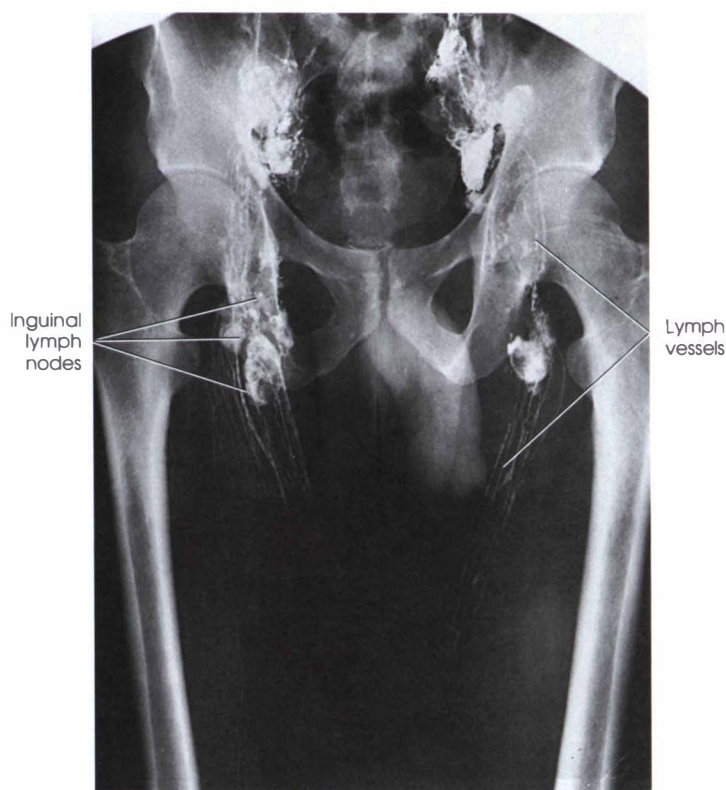
For demonstration of the lymph vessels, radiographs are made within the first hour after the contrast agent is injected. A second series of radiographs is made 24 hours later to demonstrate the lymph nodes. The exposure factors employed for lymphographic studies are the same as those used for bone studies of the respective region. Table 26-2 summarizes the most common radiographic projections and the associated anatomic structures visualized.

**TABLE 26-2**

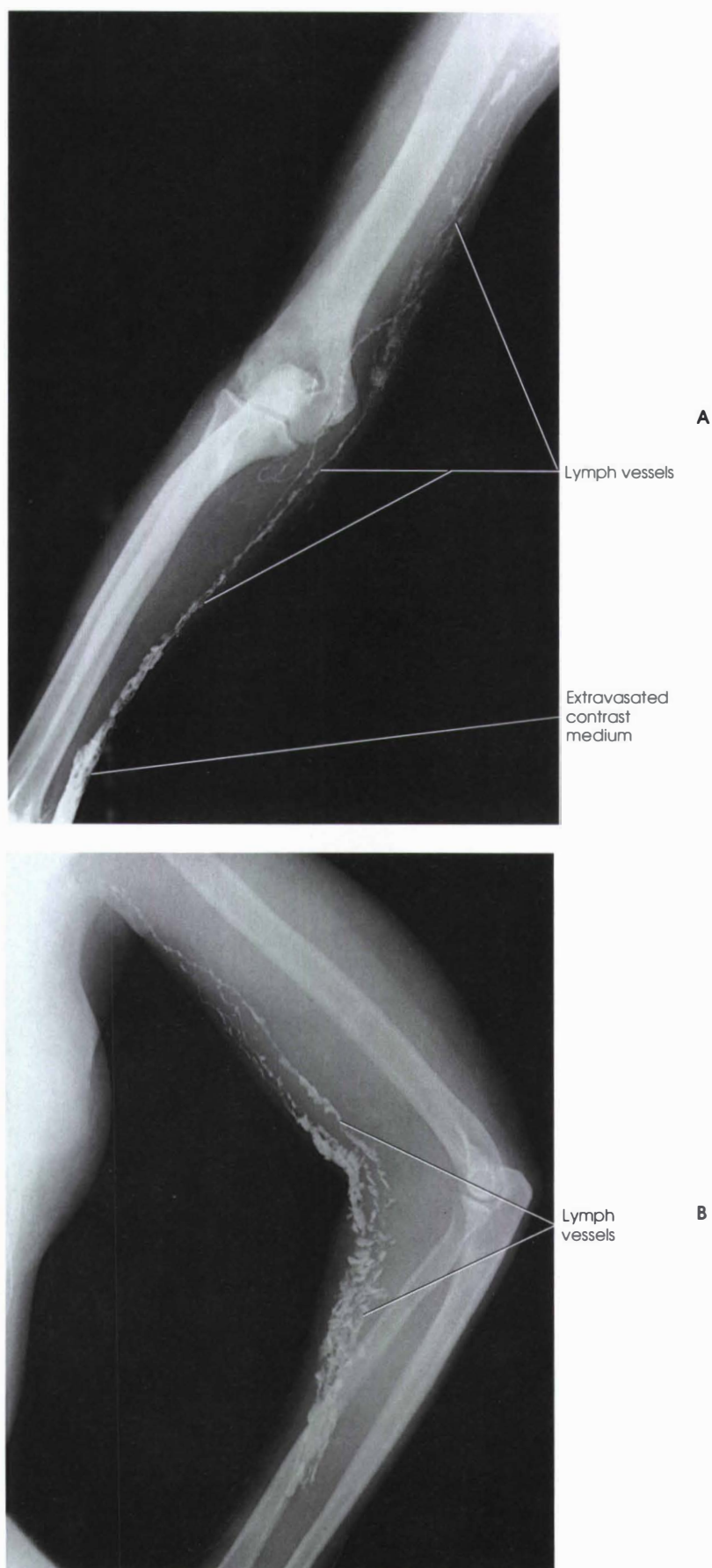
Projections and anatomy demonstrated with lymphography

Injection site	Projections	Anatomy demonstrated
Feet	AP abdomen	Iliopelvic and paraaortic lymph nodes
	RPO and LPO abdomen	
	AP thorax	Thoracic duct
	Left lateral thorax	
	Bilateral AP tibias	Lower limb lymphatic vessels
	Bilateral AP femora (see Fig. 26-91)	Inguinal lymph nodes
Hands	AP pelvis	
	AP and lateral arm (centered at elbow)	Upper limb lymphatic vessels and nodes (see Fig. 26-92)
	AP and 45 degree AP oblique shoulder	Axillary lymph nodes

AP, Anteroposterior; RPO, right posterior oblique; LPO, left posterior oblique.



**Fig. 26-91** Lymphangiogram of inguinal region and upper thighs.



**Fig. 26-92** Lymphangiograms. **A**, AP and **B**, lateral of upper limb, showing fluting of vessels and extravasation of contrast medium.



## Definitions and Indications

Photographic subtraction, introduced by Ziedses des Plantes,<sup>1</sup> is a technique by which bone structure images are subtracted, or canceled out, from a film of bones and opacified vessels, leaving an unobscured image of the vessels. The technique can be applied in all forms of angiography, wherever the vessels are superimposed in bone structures.

With the increasing popularity of digital subtraction angiography (see Chapter 35), the use of photographic subtraction has decreased in many institutions. However, photographic subtraction remains relatively widely used and is increasing in popularity in some situations. One such area of increasing frequency occurs in evaluation of joint replacements. (See the discussion of contrast arthrography in Chapter 12 of this atlas.)

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<sup>1</sup>Ziedses des Plantes BG: Subtraktion: eine roentgenographische Methode zur separaten Abbildung bestimmter Teile des Objekts, *Fortschr Roentgenstr* 52:69, 1935.

The purpose of subtraction in angiography and other specialized procedures is to fully define all vessels containing contrast material and at the same time eliminate the confusing overlying bone images. Following are a few terms that pertain to the subtraction technique:

**registration** Matching of one image over another so that bony landmarks are precisely superimposed. When so arranged, films are taped together to prevent slippage. Composites discussed herein may involve two or more films.

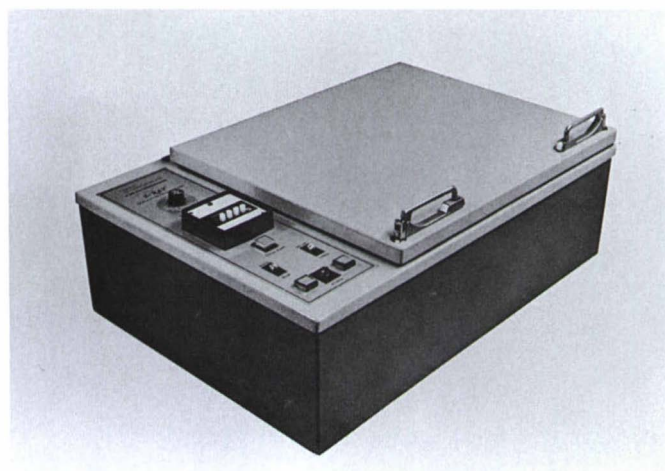
**reversal film (also called a positive mask or diapositive)** Reverse-tone duplicate of radiographic image, showing black changed to white and white to black. This positive transparency is obtained by exposing single-emulsion film through traditional radiographic film.

**zero film or base film (also called control film)** Film showing bone structures only, with no patient motion between it and subsequent contrast studies. For these reasons, zero film is exposed just before contrast medium is injected into vessels.

## EQUIPMENT AND MATERIALS

Items needed for subtraction include the following:

1. A contact printer similar to the one illustrated in (Fig. 26-93) (Several available units can also be used to duplicate radiographs.)
2. Radiographic processing facilities
3. A horizontally oriented illuminator for registration of images
4. Films—subtraction mask film for making the reversal masks and subtraction print film for making photographic prints of the final subtracted image



**Fig. 26-93** Contact printer such as that used during exposure steps in producing subtraction prints.

## First-Order Subtraction

The simplest method of photographic subtraction, called *first-order subtraction* (Fig. 26-94), consists of obtaining a positive mask, or reversal, of the first film (zero film) of the angiographic series (the one that does not contain contrast material). When the reversal mask is superimposed over a film in the series that contains contrast material, the positive and negative images of the bones tend to cancel each other out, and only the vessels are visible. The vessels are not canceled out because they were present on only one film—the one containing the contrast material. A contact printer makes a print of this combination of films.

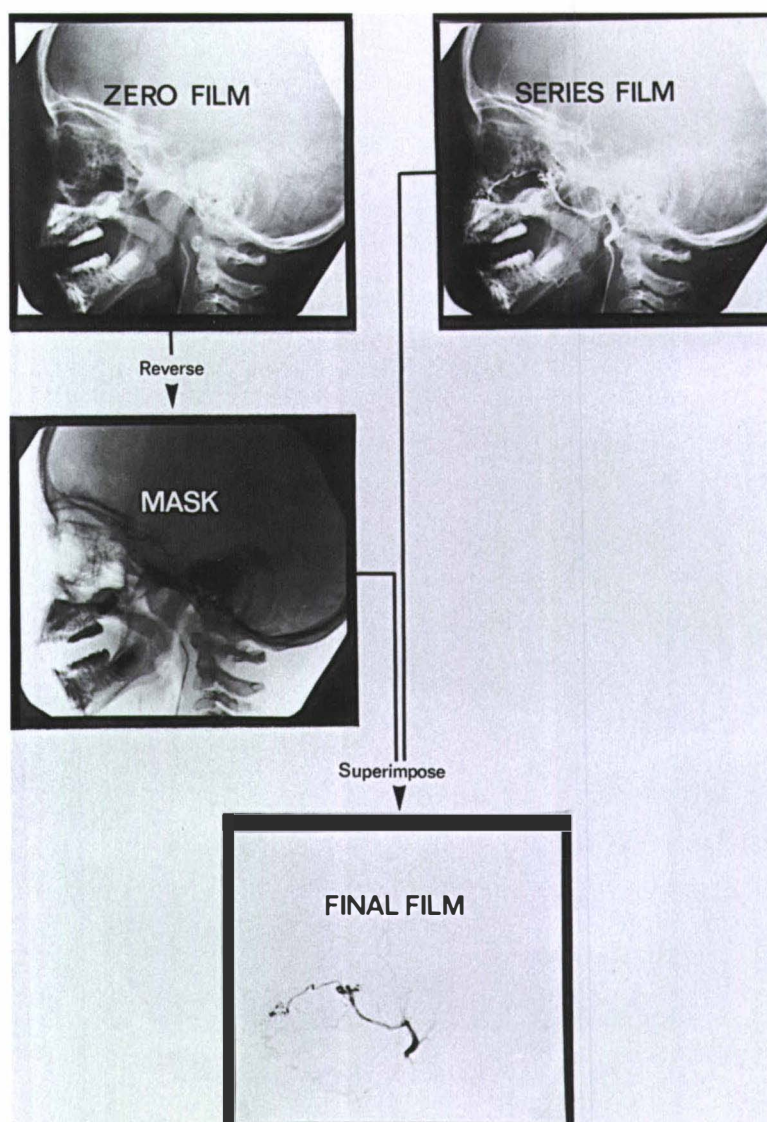


Fig. 26-94 First-order subtraction process.



## FIRST-ORDER SUBTRACTION PROCEDURE

The following steps are observed:

- In a darkroom, place the nonemulsion side of the sheet of subtraction mask film in contact with the zero film, and expose it to light for approximately 5 seconds. When processed, this becomes the mask.\*

\*Exposure time varies according to equipment and material used.

- On a light box, carefully register the mask over the selected series film (Fig. 26-95), and tape the two securely together.
- In the darkroom, place the mask-series film combination in contact with the emulsion side of a sheet of subtraction print film, and expose it to light for approximately 5 seconds.\* This produces the final subtraction image (Fig. 26-96).

\*Exposure time varies according to equipment and material used.



Fig. 26-95 Angiographic series radiograph.

## Second-Order Subtraction

The reversal of the zero film obtained in the first-order subtraction is usually not the exact reversal of the density of the selected angiographic film; thus the subtraction result is imperfect. The imperfection can be corrected with second-order subtraction. This process involves producing another film, called a *secondary* or *correction mask*, which compensates for the slight differences. Hanafee and Shinno<sup>1</sup> led the way toward this improved subtraction method. Their method of second-order subtraction consists of superimposing the zero film on its own reversal mask. The additional print that results from the transmission of light through the two films, which in theory would be the exact opposite of each other, produces a faint radiographic image that corrects for the small "photographic mistake" between the first two. The reversal of the zero film, the correction film, and the film containing contrast material are carefully registered; this combination is then exposed to obtain the final subtraction print.

<sup>1</sup>Hanafee W, Shinno JM: Second-order subtraction with simultaneous bilateral carotid, internal carotid injections, *Radiology* 86:334, 1966.



Fig. 26-96 First-order subtraction print.

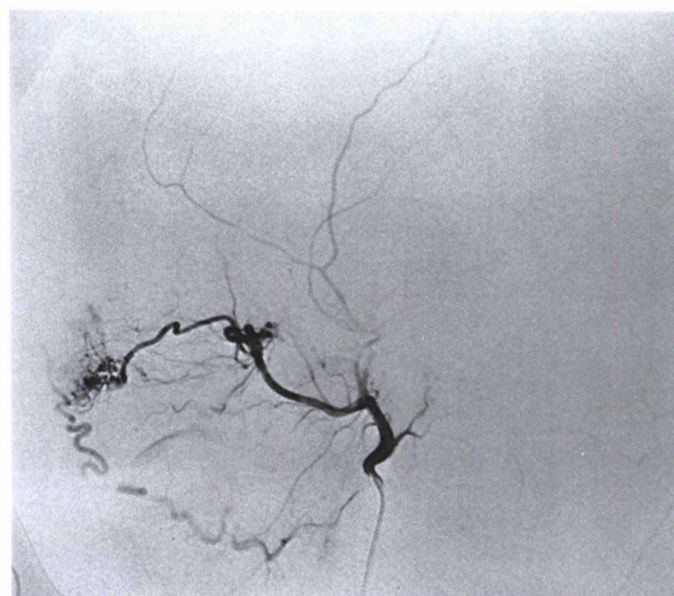


Fig. 26-97 Composite-mask, white-over-white technique. Bone has been completely removed, allowing improved visualization of vessels.



A further advancement toward the goal of complete subtraction was published by Sucher and Strand<sup>1</sup> in 1974. This second-order subtraction modification is called *composite-mask subtraction* or the *white-over-white technique*. When correctly applied, this technique almost totally eliminates both bony structures and soft tissues, leaving a display of the vessels in high-contrast reproduction (Fig. 26-97).

### COMPOSITE-MASK SUBTRACTION PROCEDURE

The following steps are illustrated in Fig. 26-98:

1. In a darkroom, place the nonemulsion side of a sheet of subtraction mask film in contact with the zero film, and expose it to light for approximately 5 seconds.\* When processed, this becomes the mask.
2. In a darkroom, place the emulsion side of a sheet of subtraction mask film in contact with the selected angiographic series film, which is then exposed to light. This process produces the series reversal film.
3. On a light box, carefully register the series reversal film with the zero film, and tape the two securely together.
4. In a darkroom, place the zero-series reversal film combination in contact with the emulsion side of a sheet of subtraction mask film, and expose it to light for approximately 20 seconds.\* This process produces the secondary mask.
5. On a light box, carefully register the series film and the mask, and tape the two securely together. Carefully register and tape the secondary mask to this composite.
6. In a darkroom, place the series film-mask-secondary mask combination in contact with the emulsion side of a sheet of subtraction print film, and expose it to light for approximately 35 seconds.\* The subtraction final film is thus produced.

<sup>1</sup>Sucher DL, Strand RD: Composite mask subtraction, white over white technique, *Radiology* 113:470, 1974.

\*Exposure time varies according to the equipment and material used.

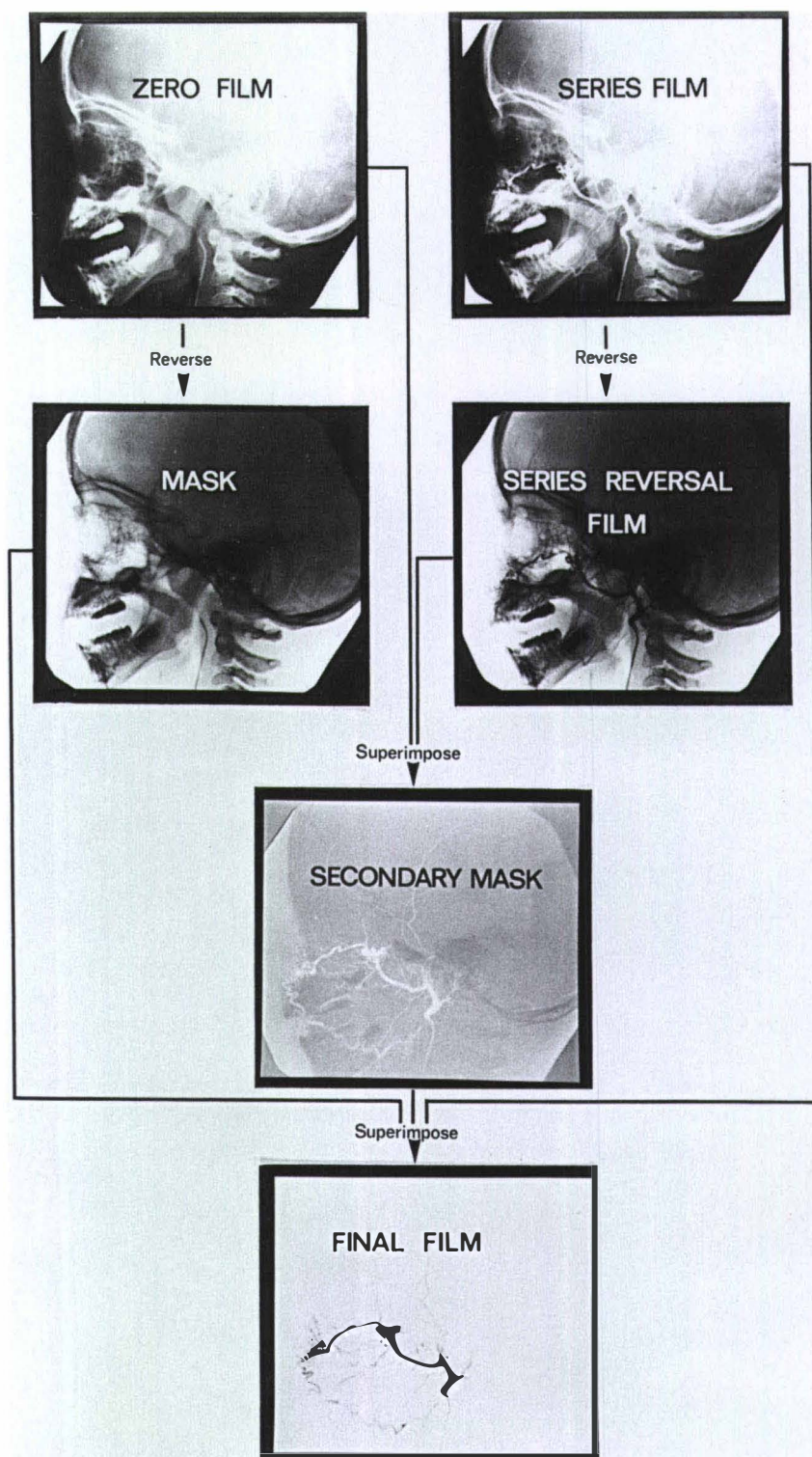


Fig. 26-98 Composite-mask subtraction process.



A comparison of second-order subtraction and composite-mask subtraction proves that the steps are almost identical. The only procedural difference is that in second-order subtraction the secondary mask is made by registering the zero film and the zero reversal mask. In composite-mask subtraction the zero film and the angiographic series reversal film are superimposed to produce the secondary mask. Although the procedures are similar, the composite-mask subtraction technique is recommended when increased resolution is required.

In recent years, marked advancement has been made in the production of films specifically designed for subtraction. In addition to the advantage of 90-second processing, these films often allow subtractions of adequate or even excellent quality to be made with the single-order subtraction technique. Composite-mask subtraction is recommended only when small structures require increased definition for visualization or when illustrations of high quality are needed for publications.

*Cardiac catheterization* is a comprehensive term used to describe a minor surgical procedure involving the introduction of specialized catheters into the heart and surrounding vasculature for the purpose of diagnostic evaluation and therapy (intervention) associated with a variety of cardiovascular-related disorders in both children and adults. Therefore cardiac catheterization is classified as either a diagnostic procedure or an interventional procedure. The primary purpose of diagnostic procedures is to collect data necessary to evaluate the patient's condition. Cardiac interventional procedures involve the application of therapeutic measures through catheter-based systems or other mechanical means to treat disorders of the vascular and conduction systems within the heart.

## Historical Development

As early as 1844, experimental placement of catheters into the hearts of animals led to the successful catheterization of both the right and left ventricles of a horse by Claude Bernard, a French physiologist. The first human cardiac catheterization was reported in 1929 by Forssman, a 25-year-old surgical resident who placed a catheter into his own heart and then walked to the radiology department where a chest radiograph was produced to document his medical achievement. Catheterization of the heart soon became a valuable tool used primarily for diagnostic purposes. Through the 1940s the basic catheterization study remained relatively uncomplicated and easy for physicians to perform; however, the risk to the patient was significant.

In the years that followed, catheterization methods and techniques increased in number and complexity and were refined. The refinements included the development of the Seldinger technique (see Fig. 26-8), and the introduction of transseptal left heart catheterization. Selective coronary *angiography* was first reported by Sones in 1959, when he inadvertently injected contrast medium into the right coronary artery of a patient who was undergoing routine aortography. In 1962 Ricketts and Abrams described the first percutaneous method for selective coronary angiography. This method was further perfected in the late 1960s with the introduction of preformed catheters designed to engage the ostium of both the right and left coronary arteries.

The 1960s and 1970s brought tremendous advances in radiologic and cardiovascular medicine and technology. Radiographic imaging and recording equipment, physiologic monitoring equipment, and cardiovascular pharmaceuticals and supplies became increasingly reliable. Since the 1970s major efforts have been made to increase the dependability, applicability, and diversity of cardiac catheterization interventional techniques. The use of computers in the catheterization laboratory has facilitated the development of this rapidly growing subspecialty of the cardiovascular medical and surgical sciences. These advances and trends have enabled cardiac catheterization to evolve from a simple diagnostic investigation to its current state as a sophisticated diagnostic study and interventional procedure.

In the early 1990s cardiac catheterization became the second most frequently performed inpatient operative procedure in the United States. More notably, it has become the most frequently performed procedure in patients over the age of 65. Currently, more than 1.5 million cardiac catheterizations are performed. Based on predictions of an increased growth in patients greater than 45 years old, it is estimated that nearly 3 million cardiac catheterization procedures will be performed annually in the United States by the year 2010.



## Principles of Cardiac Catheterization

General indications, contraindications, and risks are associated with diagnostic and interventional cardiac catheterizations. The physician must consider these factors when attempting to determine the appropriateness of any type of catheterization.

### GENERAL INDICATIONS

Cardiac catheterization is performed to identify the anatomic and physiologic condition of the heart. The data gathered during catheterization provide the physician with information to develop management strategies for patients who have cardiovascular disorders. *Coronary angiography* is currently the most definitive procedure for visualizing the coronary anatomy. The anatomic information gained from this procedure may include the presence and extent of obstructive coronary artery disease, thrombus formation, coronary artery collateral flow, coronary anomalies, aneurysms, and spasm. Coronary artery size can also be determined.

Coronary artery disease is the most common disorder necessitating catheterization of the adult heart. This disease is caused primarily by the accumulation of fatty intracoronary *atheromatous* plaque, which leads to *stenosis* and *occlusion* of the coronary arteries. Coronary artery disease is symptomatically characterized by chest pain (angina pectoris) or a heart attack (myocardial infarction [MI]). Treatment of coronary artery disease includes both medical and surgical intervention.

Diagnostic cardiac catheterization of the adult patient with coronary artery disease is conducted to assess the appropriateness and feasibility of various therapeutic options. For example, cardiac catheterization is performed before open-heart surgery to provide *hemodynamic* and *angiographic* data to document the presence and severity of disease. In selected circumstances, post-operative catheterization is performed to assess the results of surgery. An interventional procedure (such as *percutaneous transluminal coronary angioplasty* [PTCA], intracoronary stent, or atherectomy) may be indicated for the relief of arteriosclerotic coronary artery stenosis.

Diagnostic studies of the adult heart also aid in evaluating the patient who has confusing or obscure symptoms (such as chest pain of undetermined cause). These studies are also used to assess diseases of the heart not requiring surgical intervention, such as certain cardiomyopathies.

In children, diagnostic heart catheterization is employed in the evaluation of congenital and valvular disease, disorders of the cardiac conduction system, and selected cardiomyopathies. Interventional techniques are also performed in children, primarily to alleviate the symptoms associated with certain congenital heart defects.

**TABLE 26-3**

Indications for cardiac catheterization

Indications	Procedures
1. Suspected or known coronary artery disease	
a. New onset angina	LV, COR
b. Unstable angina	LV, COR
c. Evaluation before a major surgical procedure	LV, COR
b. Silent ischemia	LV, COR, ERGO
e. Positive ETT	LV, COR, ERGO
f. Atypical chest pain or coronary artery spasm	LV, COR, ERGO
2. Myocardial Myocardial infarction	
a. Unstable angina postinfarction	LV, COR
b. Failed thrombolysis	LV, COR, RH
c. Shock	LV, COR, RH
d. Mechanical complications (ventricular septal defect, rupture of wall or papillary muscle)	LV, COR, RH
3. Sudden cardiovascular death	LV, COR, R + L
4. Valvular heart disease	LV, COR, R + L, AO
5. Congenital heart disease (before anticipated corrective surgery)	LV, COR, R + L, AO
6. Aortic dissection	AO, COR
7. Pericardial constriction or tamponade	LV, COR, R + L
8. Cardiomyopathy	LV, COR, R + L, BX
9. Initial and follow-up assessment for heart transplant	LV, COR, R + L, BX

LV, Left ventriculography; COR, coronary angiography; R + L, right and left heart hemodynamics; AO, aortography; BX, endomyocardial biopsy, ERGO, ergonovine provocation of coronary spasm; RH, right heart oxygen saturations and hemodynamics (e.g., placement of Swan-Ganz catheter).

(From Kern, MJ: *The cardiac catheterization handbook*, ed. 3, St Louis, 1999, Mosby.)

The indications for cardiac catheterization as established by a special task force to the American College of Cardiology and the American Heart Association (ACC/AHA) are summarized in Table 26-3. The commonly performed procedures based on diagnosis are also presented. Furthermore, the ACC/AHA<sup>1</sup> has classified the indications and appropriateness for coronary angiography by placing the previously discussed disease categories into three classifications:

**Class 1**—Conditions for which there is general agreement that coronary angiography is justified.

**Class 2**—Conditions for which coronary angiography is frequently performed, but for which a divergence of opinion exists with respect to its justification in terms of value and appropriateness.

**Class 3**—Conditions for which coronary angiography ordinarily is not justified.

Other procedures that may be performed concurrently with coronary angiography are shown in Table 26-4. Discussion of some of these procedures occurs later in the text.

<sup>1</sup>Scanlon PJ, Faxon DP, Audet AM, et al: ACC/AHA guidelines for coronary angiography: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Coronary Angiography, *J Am Coll Cardiol* 33:1758, 1999.

**TABLE 26-4**

Procedures that may accompany coronary angiography

Procedures	Comment
1. Central venous access (femoral, internal jugular, subclavian)	Used as IV access for emergency medications or fluids, temporary pacemaker (pacemaker not mandatory for coronary angiography)
2. Hemodynamic assessment	
a. Left heart pressures (aorta, left ventricle)	Routine for all studies
b. Right and left heart combined pressures	Not routine for coronary artery disease; mandatory for valvular heart disease; routine for congestive heart failure (CHF), right ventricular dysfunction, pericardial diseases, cardiomyopathy, intracardiac shunts, congenital abnormalities
3. Left ventricular angiography	Routine for all studies, may be excluded with high-risk patients, left main coronary or aortic stenosis, severe CHF
4. Internal mammary selective angiography	Not routine unless used as coronary bypass conduit
5. Pharmacologic studies	
a. Ergonovine	Routine for coronary vasospasm
b. IC/IV/ Sublingual nitroglycerin	Optionally routine for all studies
6. Aortography	Routine for aortic insufficiency, aortic dissection, aortic aneurysm, with or without aortic stenosis, routine to locate bypass grafts not visualized by selective angiography
7. Digital subtraction angiography	Not routine for coronary angiography; excellent for peripheral vascular disease
8. Cardiac pacing and electrophysiologic studies	Arrhythmia evaluation
9. Interventional and special techniques	Intracoronary flow-pressure for lesion assessment Coronary angioplasty (PTCA) Myocardial biopsy Transseptal or direct left ventricular puncture Balloon catheter valvuloplasty Conduction tract catheter ablation
10. Arterial closure devices	Available for patients with conditions prone to puncture site bleeding

(From Kern, MJ: *The cardiac catheterization handbook*, ed. 3, St Louis, 1999, Mosby.)



**CONTRAINDICATIONS, COMPLICATIONS, AND ASSOCIATED RISKS**

Cardiac catheterization has associated inherent risk factors. However, many physicians agree that the only absolute contraindications to this procedure are the refusal of the procedure by a mentally competent person, and the lack of adequate equipment or catheterization facilities.

Contraindications for cardiac catheterization are relatively few when the appropriateness of the procedure is based on the benefit-risk ratio. Relative contraindications according to the guidelines of the ACC-AHA<sup>1</sup> include the following:

- Active gastrointestinal bleeding
- Acute or chronic renal failure
- Recent stroke
- Fever from infection or the presence of an active infection
- Severe electrolyte imbalance
- Severe anemia
- Short life expectancy because of other illness
- Digitalis intoxication

<sup>1</sup>Scanlon PJ, Faxon DP, Audet AM, et al: ACC/AHA guidelines for coronary angiography: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Coronary Angiography, *J Am Coll Cardiol* 33:1761, 1999.

- Patient refusal of therapeutic treatment such as PTCA or bypass surgery
- Severe uncontrolled hypertension
- Coagulopathy and bleeding disorders
- Acute pulmonary edema
- Uncontrolled ventricular arrhythmias
- Aortic valve endocarditis
- Previous anaphylactic reaction to contrast media

Some of these conditions may be temporary, or they may be treated and reversed before cardiac catheterization is attempted. Cardiac catheterization may proceed if any of the above conditions exist on a patient who is deemed to be unstable from a suspected cardiac cause.

As with any invasive procedure, complications can be expected during cardiac catheterization. The Society for Cardiac Angiography and Interventions (SCA&I) reviewed the catheterizations in over 300,000 patients from three different time periods and found the major complication rate for the entire group was <2%. Those complications are shown in Table 26-5. The risks associated with cardiac catheterization have decreased since the early days of the procedure. However, as the severity of the patient's disease increases so do the risks associated with the procedure. The risks of cardiac catheterization vary according to the type of procedure and the

status of the patient undergoing the procedure. Significantly influencing the outcome of the procedure is the stability of the patient prior to the procedure. For example, patients presenting with left main coronary stenosis have a greater than twofold higher risk of complications from coronary angiography than those who have no left main coronary stenosis. The SCA&I database identified the main predictors of major complications following cardiac catheterization and determined that the following increased the risk of complications.<sup>1</sup>

- Moribund patient (patient with poor response to life threatening condition)
- Cardiogenic shock
- Acute myocardial infarction (within 24 hours)
- Renal insufficiency
- Cardiomyopathy

Risk variables of less significance include, the anatomy to be studied; type of catheter and approach used; history of drug allergy; presence of basic cardiovascular disease or non-cardiac disease such as asthma or diabetes; hemodynamic status; and age or other patient characteristics.

Therefore the benefits expected to be derived from cardiac catheterization must be weighed against the associated risks of the procedure when determining to perform the procedure.

<sup>1</sup>Laskey W, Boyle J, Johnson LW: Multivariable model for prediction of risk of significant complication during diagnostic cardiac catheterization: the Registry Committee of the Society for Cardiac Angiography and Interventions, *Cathet Cardiovasc Diagn* 30:185, 1993.

**TABLE 26-5**  
Comparison of major complications for diagnostic catheterization

	1979-1998 (N= 53,581 pts) Percent	1984-1987 (222,553 pts) Percent	1984-1987 (59,792 pts) Percent
Death	0.14	0.10	0.11
MI	0.07	0.06	0.05
CVA (neurologic)	0.07	0.07	0.07
Arrhythmia	0.56	0.47	0.38
Vascular	0.57	0.46	0.43
Hemorrhage	—	0.07	—
Contrast	—	0.23	0.37
Hemodynamic	—	—	0.26
Perforation	—	—	0.03
Other	0.4	0.28	0.28
Total	1.77	1.74	1.70

(From Noto TJ, Johnson LW, Krone R, et al: Cardiac catheterization 1990: a report to the Registry of the Society for Cardiac Angiography and Interventions (SCA&I), *Cathet Cardiovasc Diagn* 24:75, 1991.)

## Specialized Equipment

Cardiac catheterization has developed into a highly complex, sophisticated procedure requiring specialized equipment and supplies. Unlike earlier radiographic examinations of the intracardiac structures, modern cardiac catheterization requires more than a simple fluoroscope and a recording modality such as that used in overhead radiography.

Equipment and supplies required for cardiac catheterization can be categorized in three groups: (1) angiographic supplies and equipment, (2) imaging, and (3) ancillary equipment and supplies. The following are examples of equipment typically contained in each group.

### ANGIOGRAPHIC SUPPLIES AND EQUIPMENT

Cardiovascular equipment consists of those supplies and equipment needed to perform the procedure. As a result of the complexity and types of procedures performed in a cardiac catheterization lab only a few of the main component items are discussed.

#### Needles

Vascular access needles are necessary when performing percutaneous cardiovascular procedures. Needle size is based on the external diameter of the needle and is assigned a gauge size. However, to allow for appropriate guidewire matching, the internal diameter of the needle must be known. Vascular access needles come in different types, sizes, and lengths. The most commonly used access needle for adult cardiovascular procedures is an 18-gauge needle that is 2.75 inches long. This particular needle is compatible with a 0.035 guidewire, which is the most frequently used guidewire in cardiovascular procedures. Appropriate needle size is predicated on the type of size of guidewire needed, the size of the patient, and the targeted entry vessel. To decrease the chances of vascular complications the smallest gauge needle that meets the above criteria is used for vascular access. Access needles for the pediatric patient come in smaller gauge sizes with shorter lengths (Fig. 26-99).

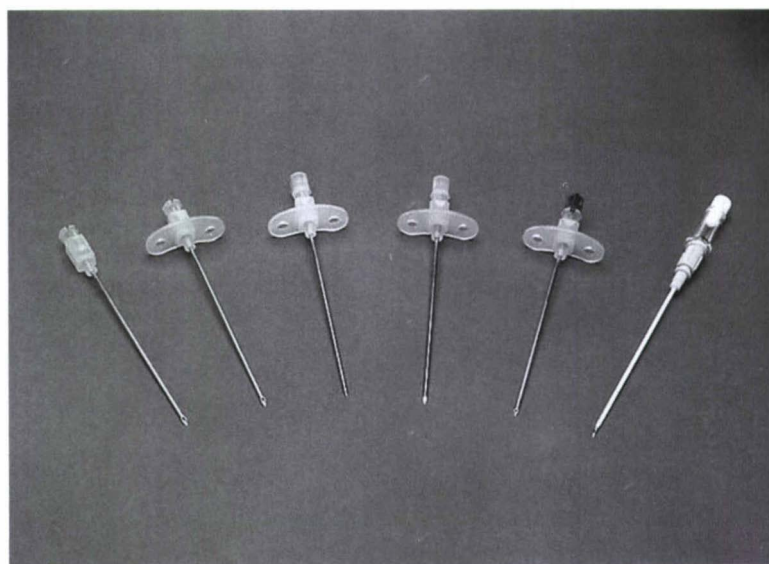


Fig. 26-99 Various needles utilized during cardiac catheterization.

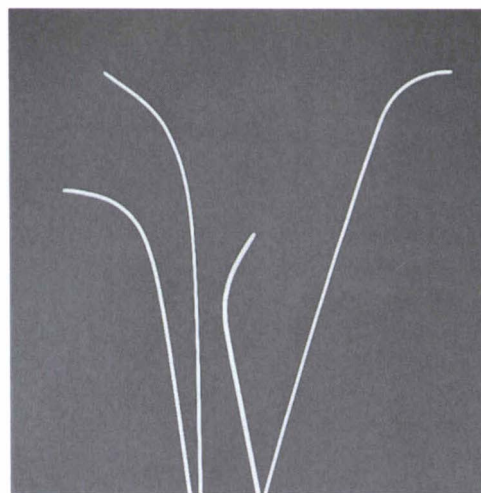


## Guidewires

*Guidewires*; also commonly referred to as a spring guide or wire guide are used in angiography and other special procedures as a platform for the catheter to be advanced over. To decrease the possibilities of complications the guidewire should be advanced into the vasculature ahead of the catheter. Once positioned in the area of interest the guidewires position is fixed and the catheter advanced until it meets the tip of the guidewire. Similar to needles, guidewires come in a variety of sizes, shapes, and lengths and care must be taken to match the proper guidewire to the selected access needle and catheter.

The majority of guidewires are constructed of stainless steel, with a core or mandrel encased circumferentially within a tightly wound spiral outer core of spring wire. The mandrel gives the guidewire its stiffness and body. The length of the mandrel within the wire determines the flexibility of the wire. The shorter the mandrel the more flexible the wire and the more likely it is to traverse tortuous anatomy. A safety ribbon is built into the tip of the guidewire to prevent wire dislodgement in case the wire should fracture. Many of the stainless steel guidewires are coated with Teflon to provide lubricity and decrease the friction between the catheter and wire. Similarly it is felt that the Teflon coating helps to decrease the thrombogenicity of the guidewire.

More recently plastic alloy guidewires consisting of a hydrophilic plastic polymer coating have been introduced. These new wires provide a very smooth outer coating, with a pliable tip and exhibit a very high degree of torque or maneuverability (Fig. 26-100).



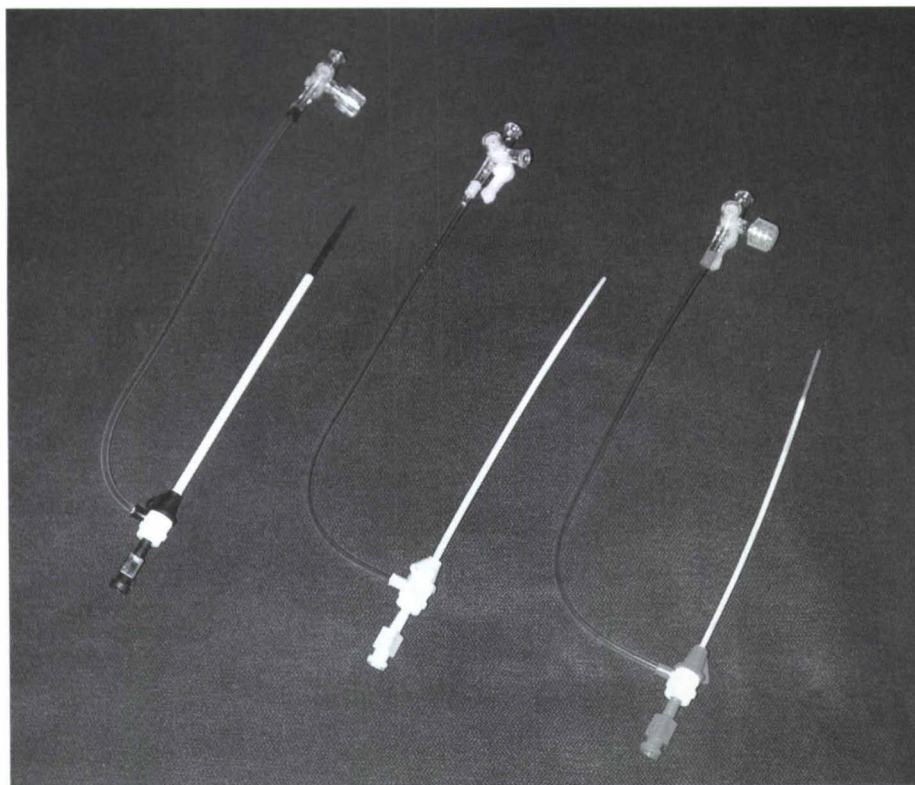
**Fig. 26-100** The hydrophilic guidewire is a special type of guidewire that allows the user a high degree of torque and maneuverability. Like other guidewires, it is offered in various lengths and shaped tips. A special type of guidewire that allows the user a high degree of torque and maneuverability.

### Introducer sheaths

*Introducer sheaths* are frequently utilized on angiographic procedures when multiple catheters will be utilized. A variation of the previously described Seldinger technique allows the introducer sheath to be placed in lieu of the catheter during percutaneous entry of the vascular system. Once the sheath has been placed, controlled access of the vasculature is assured, while at the same time reducing vessel trauma by limiting numerous catheter passages through the vessel itself.

Introducer sheaths are short catheters consisting of a slotted rubberized backbleed valve, and a side arm extension port. The backbleed valve functions to prevent the loss of blood volume during catheter exchanges or guidewire manipulations. The side arm extension port may be utilized to infuse medications or monitor blood pressure.

Similar to vascular catheters, introducer sheaths come in various sizes and lengths. Typically, most introducer sheaths range in length from 10 to 25 cm. In terms of size it should be noted that while catheters are measured by their outside diameters and expressed in units of French size (Fr), introducer sheaths are named according to the French size catheter they can accommodate. To accomplish this the outer diameters of introducer sheaths are 1.5 to 2 Fr sizes larger than the catheter they can accept. Therefore a 5 Fr introducer, while having an outer diameter of nearly 7 Fr will accept 5 Fr catheters (Fig. 26-101).



**Fig. 26-101** Various types of sheaths utilized during cardiac catheterization. **A**, Tip of sheath. **B**, Valve portion of sheath that allows catheter to be introduced into artery and prevents back flow of blood during procedure.



### Catheters

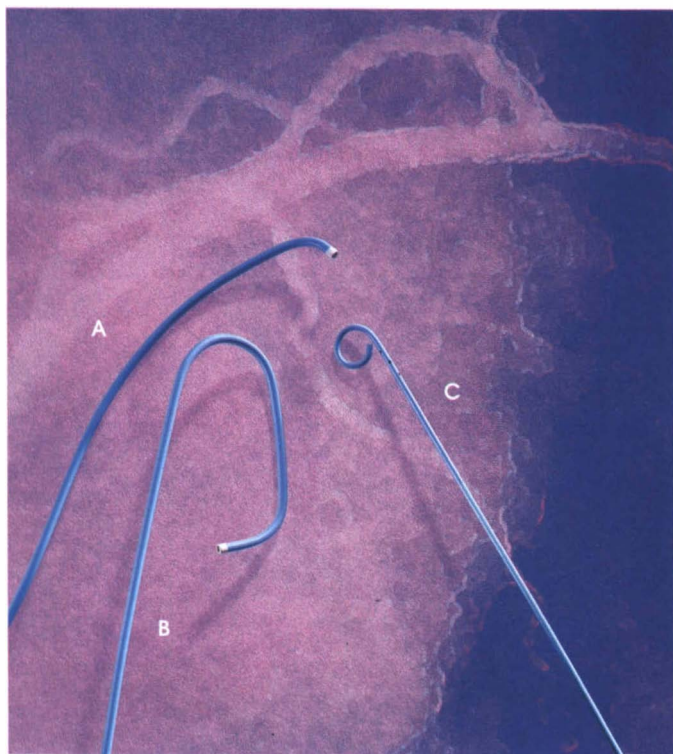
The catheters used for left heart cardiac catheterization are very similar to those angiographic catheters previously described, with the exception that cardiac catheters are preformed for the cardiac vasculature (Fig. 26-102). Specialized catheters are utilized for right heart catheterization procedures. Unlike angiographic catheters whose main purpose is as a conduit for contrast media, right heart catheters are typically flow directed catheters, which utilize an inflated balloon on the tip of the catheter to ease passage through the various chambers of the heart. Moreover various types of flow directed catheters are capable of performing more tasks than the standard angiographic catheter. Depending on the type of procedure to be performed the physician will decide which catheter to use.

Therefore the catheter (or catheters) placed in a patient's vasculature can function as a fluid-filled column for hemodynamic data or as a conduit for contrast media, thrombolytic agents, and mechanical devices. Blood samples can be drawn directly from selected cardiac chambers for the purpose of oximetry or other laboratory analysis. To perform these and other tasks, three or four valves (*stop-cocks*) are combined to form a *manifold*, which is attached to the proximal end of the catheter (Fig. 26-103). Using a manifold allows such functions as drawing blood samples, administering medications, and recording blood pressures without disconnecting from the catheter.

### Contrast media

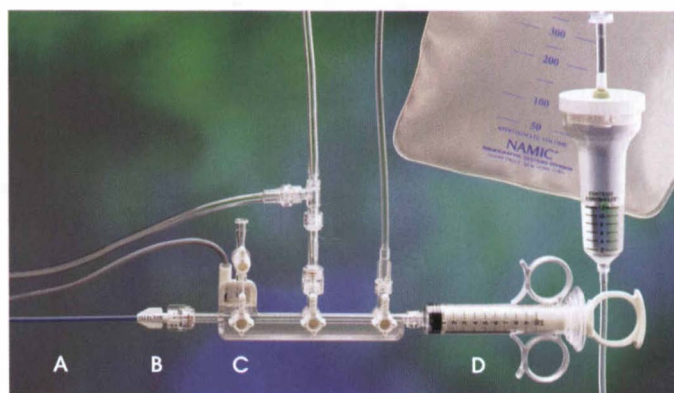
Injection of contrast media is essential for angiographic visualization of the cardiac anatomy. Several iodinated radiographic contrast media are approved for intravascular, intracardiac, and intracoronary use in both adults and children. However, many of these high-osmolar ionic contrast media have been noted to cause hemodynamic and electrophysiologic effects during administration. Transient (temporary) ECG changes during and immediately after the injection of contrast medium are common.

Less viscous (low-osmolar), nonionic contrast agents that were developed in the 1980s have been found to exhibit the same radiopacity as their counterparts. Because of their properties, nonionic contrast media and ionic low-osmolar contrast media have gained acceptance and are now used in many cardiac catheterization laboratories. Nonionic contrast media have some definite advantages over ionic high-osmolar contrast media. For example, they are associated with a reduced incidence of cardiovascular reactions and side effects as a result of their lower osmotic pressure. Unfortunately, the newer contrast media are considerably more expensive. Due to their cost most catheterization laboratories now restrict the use of the low-osmolality agents for those patients who are considered to be at a higher risk for contrast agent reactions.



**Fig. 26-102** Catheters used during cardiac catheterization: **A**, Judkins right; **B**, Judkins left; **C**, Pigtail.

(Courtesy Cordis Corp., Miami, Fla.)



**Fig. 26-103** Disposable 3 valve Compensator Morse manifold, with a Selector catheter (**A**), rotating adapter (**B**), pressure transducer (**C**), and angiographic control syringe (**D**).

(Courtesy SCHNEIDER/NAMIC, Glens Falls, New York.)

### Pressure injector

The pressure injector for the administration of radiographic contrast medium (Fig. 26-104) as previously discussed in injection techniques is also used during cardiac catheterization. In the catheterization laboratory the pressure injector is used to inject a large amount (25 to 50 ml) of contrast material into either the right or left ventricle (the main pumping chambers of the heart), the aortic root, or the pulmonary vessels. Since the coronary arteries are of small caliber and of low flow rates administration of contrast medium into these structures generally does not require a high-pressure injector. Instead, most physicians opt for manual injection utilizing an angiographic control syringe (see Fig. 26-103).

### IMAGING

#### Image chain

The imaging equipment found in the cardiac catheterization laboratory is essentially the same as that found in the vascular angiography suite. The catheterization laboratory requires a system capable of producing fluoroscopic images with the greatest amount of recorded detail available. Maximum resolution from the optical system is crucial due to the small size of the cardiac anatomy, which must be imaged while in motion.

Angiographic x-ray tubes must be capable of producing ionizing radiation for the long periods of time necessary for fluoroscopy, and therefore must be designed to withstand greater heat loading. Ideally angiographic tubes should have a heat load capacity of 1.5 million heat units or greater. For most cardiac imaging, multifocal-spot, high-speed rotating fluoroscopic tubes are desirable. Extremely short exposure times are required to accommodate the rapid-exposure sequencing of the various recording systems.

A high-resolution imaging and recording system requires several pieces of equipment, including an image intensifier tube. This tube should produce the maximum recorded detail necessary for cardiac catheterization. The image intensifier used in the cardiac catheterization laboratory generally comes with three different field of view modes (5 in, 7 in, 9 in) to allow for enhanced visualization of small anatomic structures. A video camera is optically coupled to the output phosphor of the image intensifier, and its signal is fed to television monitors placed so that the fluoroscopic images can be easily viewed during the procedure.



**Fig. 26-104** The Angiomat (ILLUMENA) high-pressure injector for radiographic contrast medium.

(Courtesy Liebel-Flarsheim, a product of Mallinckrodt, Inc., Cincinnati, OH.)



### Cineangiographic and videotape image recording

For many years cineangiography systems have been the major means of recording cardiac catheterization images on film in the cardiac catheterization lab. Permanent recording of the cineangiographic image is made on 35-mm black-and-white movie film. For this purpose, a high-resolution motion picture cine camera is linked to the image intensifier. A mirror near the output phosphor of the image intensifier allows the simultaneous splitting of the image to a video camera and a 35-mm cine camera. The cine camera is synchronized to the x-ray tube to record the image at 30 or 60 frames per second. In general this synchronization requires exposure times in adults between 4 to 8 ms, and 2 to 4 ms in children. Following the procedure, cine films must be processed similar to any other x-ray image. The dynamic motion of the heart as recorded on the cine film is then projected on a cine projector which offers a virtually flicker free image.

The video camera allows the image that is being captured on cine film to be displayed concurrently on a television monitor. The image from the video camera may also be archived to a videotape player and later used for instant replay of any of the previously recorded images.

### Digital angiography imaging equipment

Digital angiography has gained universal acceptance in the catheterization laboratory. Digital imaging now produces resolution comparable with that of the 35-mm cineangiographic film image. The resolution possible with early digital equipment was a drawback to the use of digital imaging in the catheterization laboratory. Larger matrix size, the obvious solution to this problem, allowed for acceptable resolution but also created another problem: how to acquire and store large volumes of digital information.

In the late 1970s and early 1980s the high-speed parallel transfer disk was introduced to solve the acquisition and short-term storage problem. This new disk acquired and stored an entire coronary angiogram and made real-time digital playback during the procedure possible. However, permanent storage of the digital images remained a problem. Floppy disk and computer tape storage were not adequate solutions because they required significant amounts of time and supplies.

Recently long-term storage of large amounts of digital images has benefited from advances in computer technology. Larger hard drives, digital tape storage, optical disks, compact discs, and digital video disks (DVD) are a few of the new storage media. These storage devices provide a high-speed, large-capacity method of storage, capable of acquiring large amounts of data (32 gigabytes [GB]) with very high resolution. However, the long-term stability of these media has not been tested, and the need to routinely update the images recorded on them have been raised.

Today the cineangiography versus digital question is solved through the use of simultaneous acquisition technology, which means that cineangiographic film and digital images are acquired at the same time. Although this method is counterproductive to the goal of eliminating cost associated with cine film, it does serve to ensure long term archival of acquired images. This technology combines the practicality of 35-mm cineangiographic film with the image manipulation and analysis capabilities (e.g., left ventricular ejection fraction calculations, coronary artery stenosis sizing) of digital angiograms. A problem incumbent with digital imaging is the incompatibility of the storage media from one system to the other. As more laboratories are becoming equipped with digital systems, the tendency has been to configure digital systems that can be easily updated and interfaced to image networks. A committee composed of industry representatives was established to set standards for digital imaging. The *Digital Communications Committee* (DICOM) has set guidelines for a universal exchange standard in digital imaging. The committee determined that the compact disc recordable (CD-R) would be the preferred storage medium for single-patient study transfer between institutions. The CD-R, which is the same

size as the compact disc read-only memory (CD-ROM), is a one-time recording medium capable of storing 650 megabytes (MB) of information. Because the CD-R can store such a large amount of information, it is quickly becoming the equivalent of a cineangiography film. Applications involving DVD are still evolving. Eventually it will be possible to store up to 14 GB of information on one DVD. Following the introduction of the computer in medicine, the practice and development of radiologic procedures rapidly expanded. Specifically in procedures involving this chapter, the computer assisted in major advancements. Due to space considerations in this edition, the "Computer Fundamentals and Applications in Radiology" chapter has been deleted. For those interested in learning more about computer fundamentals, please see Volume 3, Chapter 32 of the eighth or ninth editions of this Atlas. One disadvantage of the CD-R is the need to purchase the equipment to download and play back the images. Currently all catheterization laboratories have a cineangiographic projector to view 35-mm film angiograms, but not every catheterization laboratory has the equipment necessary to view the CD-R. Until all laboratories have the equipment to meet the DICOM standard, cineangiographic imaging will continue to be used.

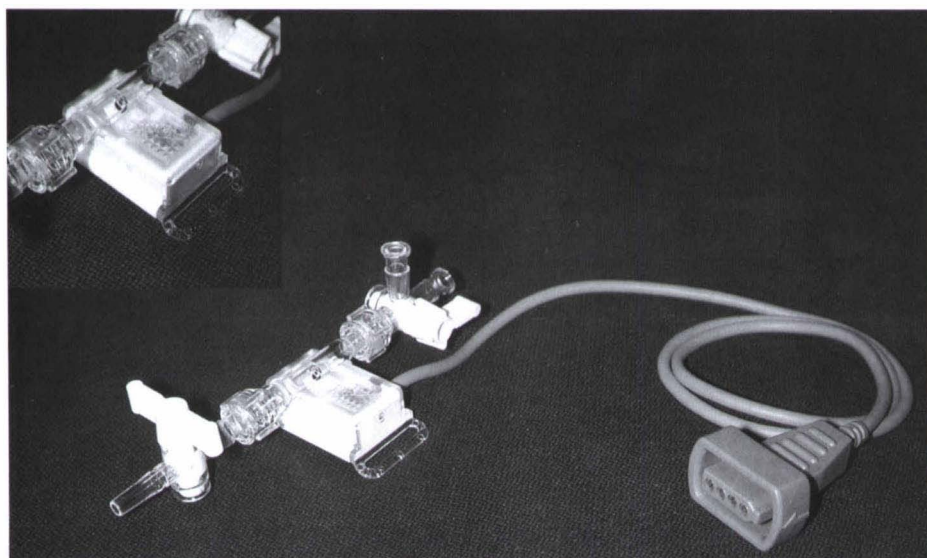
The speculation that digital imaging systems will someday replace cineangiography film as the standard for cardiac catheterization imaging is now nearly a reality. Problems regarding ways to transport and view digital images easily have been addressed by the DICOM standard. To conform to this standard, equipment manufacturers continue to produce digital products that can be accessed by any other manufacturer's product line.





**Fig. 26-105** Computer-based physiologic monitor used to monitor patient ECG and hemodynamic pressures during cardiac catheterization.

(Courtesy Quinton Instrument Co., Bothell, WA)



**Fig. 26-106** The pressure transducer is connected to a catheter such that a patient's pressure is transmitted along the catheter and converted to an electrical signal that is displayed on a monitor. Inset upper left-hand corner displays a close up of the part of the transducer that converts the fluid pressure to an electrical signal.

## ANCILLARY EQUIPMENT AND SUPPLIES

### Physiologic equipment

The physiologic monitor is essential to cardiac catheterization procedures. It is used to monitor and record vital patient functions, including electrical activity (ECG or EKG)\* within the heart and blood pressure (hemodynamic) within the various intracardiac chambers (Fig. 26-105). The patient's ECG and hemodynamic pressures are continuously displayed throughout the various types of procedures. (Selective samplings of ECG and hemodynamic pressures are recorded for permanent documentation.)

For the collection of hemodynamic data during catheterization, the physiologic recorder (receiving information in electrical form) must be connected to the catheter (carrying information as physical fluid pressure). Devices called pressure transducers are interfaced between the manifold and the physiologic recorder to convert fluid (blood) pressure into an electrical signal (Fig. 26-106).

For a standard cardiac catheterization procedure, four channels of the physiologic recorder are usually prepared: two for ECG recordings and two for pressure recordings. However, a physiological recorder can have as many as 32 channels. A channel, or module, is an electrical component of the physiologic recorder that is capable of measuring an individual parameter such as a specific type of ECG or intravascular pressure. The number of channels required for a particular catheterization increases as the amount of detailed information required increases. Increasingly these monitoring systems are produced with detailed procedural databases for the collection and maintenance of patient clinical data as well as the concurrent generation of a procedural report at the time of catheterization.

\*Interpretation of ECG is beyond the scope of this chapter; however, a reference has been listed in the selected bibliography.

### Other equipment

Because of the nature of the patient's condition, the inherent risks of cardiac catheterization, and the types of procedures performed each catheterization room should have the following equipment available:

- A fully equipped emergency cart. The cart typically contains emergency medications, cardiopulmonary resuscitation equipment, intubation equipment, and other related supplies.
- Oxygen and suction.
- Whole blood oximeters, utilized to determine the oxygen saturation of the blood samples, obtained during adult and pediatric catheterizations (Fig. 26-107).
- Defibrillator, utilized to treat life-threatening arrhythmias. Ideally, the defibrillator would also have external pacemaking capabilities.
- Temporary pacemaker to treat potential asystole or symptomatic bradycardia.
- Pulse oximeter to noninvasively monitor and assess level of oxygenation during sedation.
- Non-invasive blood pressure cuff.
- Equipment to perform cardiac output studies.
- Intraaortic balloon pump console and catheters to treat cardiogenic shock.
- ACT machine to measure levels of heparinization during interventional procedures.



**Fig. 26-107** Oximeter used to measure oxygen saturation in blood.

(Courtesy Instrumentation Laboratories, Lexington, Mass.)



## Patient Positioning for Cardiac Catheterization

Procedures such as selective coronary arteriography and certain pediatric catheterizations require imaging equipment to be positioned to reduce the superimposition created by the cardiac vasculature. Moving the patient during the catheterization is not desirable, particularly when catheters have been carefully positioned to demonstrate specific anatomic structures or to record certain data.

In most catheterization laboratories the image intensifier and fluoroscopic tube are mechanically suspended in a C-arm configuration to allow for equipment rotation around the patient and to provide cranial or caudal angulation. In this configuration the image intensifier is above the plane of the table, and the fluoroscopic tube is beneath the table. During catheterization procedures the patient is placed on the examination table in a supine position. For optimal images, the imaging equipment should be rotated around the patient. In some interventional procedures, biplane C-arms are advantageous because they allow simultaneous imaging of cardiac structures in two different planes (Fig. 26-108, A, and Fig. 26-108, B).

Adult and pediatric coronary anatomy has both normal and pathologic variations. Therefore projections for each type of catheterization procedure cannot be specified. Instead, each patient's anatomy must be fluoroscopically evaluated to ascertain the optimum degree of rotation and cranial or caudal angulation necessary to visualize each structure of interest.

## Catheterization Methods and Techniques

Different cardiac catheterizations require various combinations of methods and techniques to allow for precise data acquisition and the application of therapeutic interventions. Some methods and techniques common to most cardiac catheterizations are discussed in the following sections.

### PRECATHETERIZATION CARE

Before the catheterization is performed, the procedure is explained and informed consent is obtained. Testing before catheterization normally includes the following:

- Patient history
- Physical examination
- Chest x-ray examination
- Blood work
- ECG
- Echocardiogram
- Exercise stress test

Various medications are frequently administered for sedation and control of nausea.

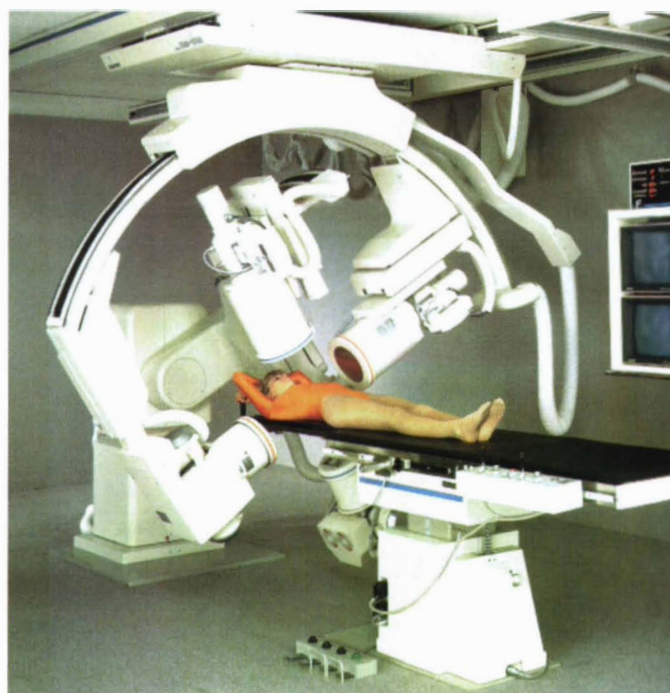
Patients brought to the catheterization laboratory typically are not allowed anything to eat or drink for 4 to 6 hours before the procedure. During all catheterizations a protocol, or detailed record, of the procedure is maintained. The record includes hemodynamic data, fluoroscopy time, medications administered, supplies used, and other pertinent information.

### CATHETER INTRODUCTION

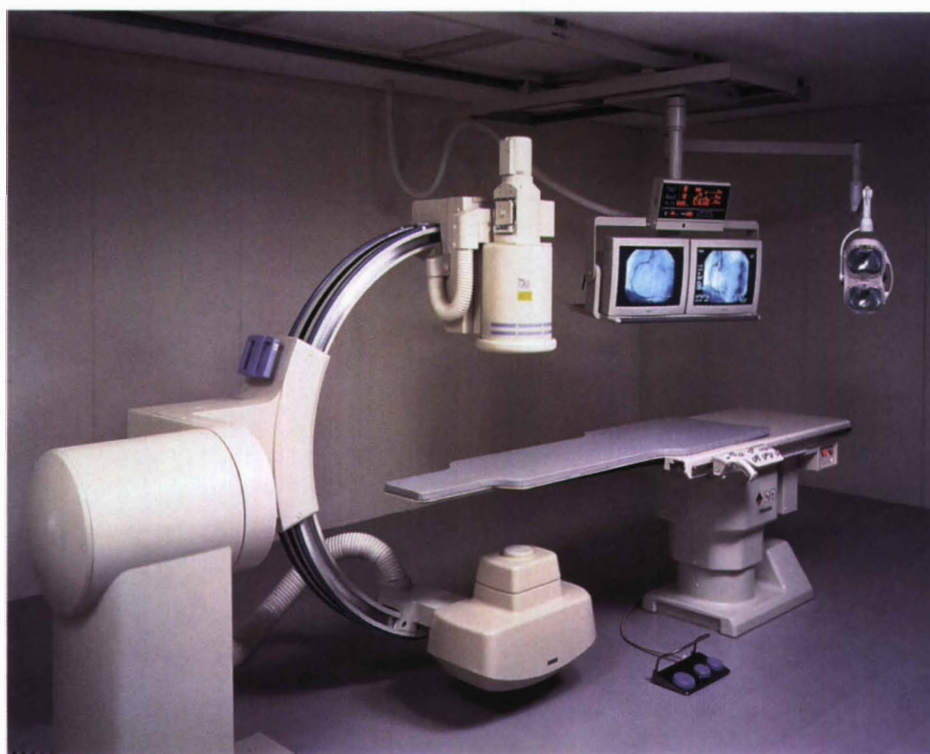
After the patient has been transported to the catheterization laboratory, ECG, non-invasive blood pressure monitoring, and, in some institutions, *pulse oximetry* are initiated. The appropriate site for catheter introduction must be prepared using aseptic technique to minimize the risk of subsequent infection. The area of the body to be entered is shaved, and an antiseptic solution is applied. Numerous sites can be used for catheter introduction. The specific sites vary according to the age and body habitus of the patient, the preference of the physician, and the procedure attempted. The most frequent site utilized for catheterization is the femoral area. However, the radial, brachial, axillary, jugular (neck), and subclavian (chest) area may also be utilized.

For catheterization of the femoral artery or vein, the percutaneous approach is employed (see the Seldinger technique, which is described and illustrated in Fig. 26-8). Once vascular access is obtained an introducer sheath is placed over the guide wire and advanced into the vessel. This creates a controlled access into which catheters may be introduced with very little blood loss. The catheter is placed over the guide wire and advanced toward the heart. The guide wire may be removed or temporarily left in place to facilitate further placement of the catheter. When the catheter is in the proper position, the guide wire is removed, the catheter is connected to the manifold, and the coronary angiogram may begin.

If the percutaneous approach cannot be used, a cut-down technique is employed. This technique requires that a small incision be made in the skin to allow for direct visualization of the artery or vein the physician wants to catheterize. The skin is aseptically prepared and infiltrated with local anesthetic, and the vessel or vessels are bluntly dissected and exposed. After an opening is created in the desired vessel (arteriotomy or venotomy), the catheter is introduced and advanced toward the heart. Cut-down procedures are frequently performed in the right antecubital fossa to access the basilic vein or brachial artery.



A



B

**Fig. 26-108** **A**, Biplane radiology equipment used in the cardiac catheterization laboratory; **B**, modern single-plane digital catheterization with "smart handle" technology.

(Courtesy Toshiba America Medical Systems.)





Fig. 26-109 Simulated electrocardiogram (*top*) and aortic pressure (*bottom*).

(Courtesy Quinton Instrument Co., Bothell, Wash.)

## DATA COLLECTION

The acquisition of certain data is essential, regardless of the type of catheterization performed. Physiologic data typically collected include hemodynamic parameters, ECG, and oximetry readings.

Hemodynamic parameters include blood pressure and cardiac output. The monitoring and recording of both intracardiac (within the heart) and extracardiac (outside the heart) vascular pressures require the use of the physiologic-transducer system described previously in this chapter. Cardiac output, an important indicator of the overall ability of the heart to pump blood, can be measured in the catheterization laboratory. Several methods are used to obtain estimates of cardiac output. The ECG is continuously monitored during catheterization and can be simultaneously recorded with intracardiac or extracardiac pressures (Fig. 26-109). Blood samples are obtained from the various chambers of the heart to determine oxygen saturation levels and the presence of any intracardiac shunts.

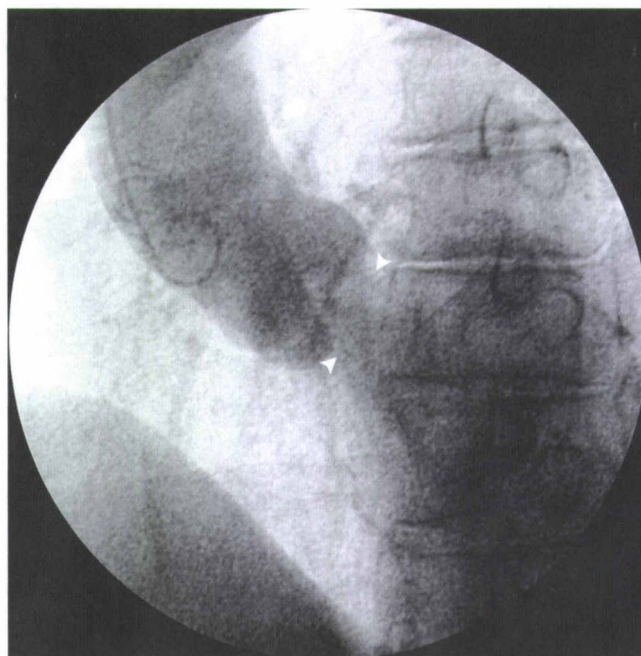
## Catheterization Studies and Procedures

The primary purpose of the diagnostic cardiac catheterization is data collection, while the primary purpose of the interventional procedure is therapy. The following sections briefly describe some of the more commonly performed diagnostic and interventional heart catheterizations.

### BASIC DIAGNOSTIC STUDIES OF THE VASCULAR SYSTEM

#### Adults

Catheterization of the left side of the heart is a widely performed, basic diagnostic cardiac study. The catheter may be introduced through the radial, brachial, or femoral artery, and advanced over a guidewire to the ascending aorta. Once in the ascending aorta the guide wire is removed and the catheter aspirated and flushed to prevent migration of any air bubbles. Aortic root angiography may be performed to document the competence of the aortic valve. A normal aortic valve prevents backward flow of contrast media into the left ventricle during injection, while an insufficient valve does not (Fig. 26-110). Arterial oximetry and blood pressure measurements within the aorta are taken utilizing the manifold system. Once this has been accomplished the catheter is passed through the aortic valve into the left ventricle.



**Fig. 26-110** Left ventriculogram demonstrating aortic insufficiency with contrast flowing back into left ventricle (*white arrowheads*).



Once again, arterial oximetry is performed, and blood pressure measurements are taken in the left ventricle. Angiography of the left ventricle is performed in nearly all catheterization studies of the left side of the heart (Fig. 26-111). Left ventriculography provides information about valvular competence, interventricular septal integrity, and the efficiency of the pumping action of the left ventricle (ejection fraction). Mitral regurgitation is another example of valvular incompetence and angiographically it is seen as the backward flow of contrast media from the left ventricle into the left atrium or pulmonary veins (Fig. 26-112). The *ejection fraction (EF)* of the left ventricle is determined angiographically by superimposing images of the left ventricle at end *diastole* and at end *systole* and expressed as a percentage. Computer *planimetry* software, which is now available on most digital systems,

then calculates how well the ventricle functions (Fig. 26-113). Following left ventriculography, the presence of aortic valve stenosis is determined as the blood pressure measurements are repeated as the catheter is withdrawn across the aortic valve. Normal flow of blood through the aortic valve allows the systolic pressure in the left ventricle to match the systolic pressure in the aorta. When the systolic blood pressure in the left ventricle is greater than the systolic blood pressure in the aorta, aortic stenosis is present (Fig. 26-114).

Following a catheter exchange selective angiography of the right coronary artery and left coronary artery is performed, with different projections used for each coronary artery to prevent superimposition with overlapping structures. Coronary angiography allows the extent of intracoronary stenosis to be evaluated (Figs. 26-115 and 26-116).

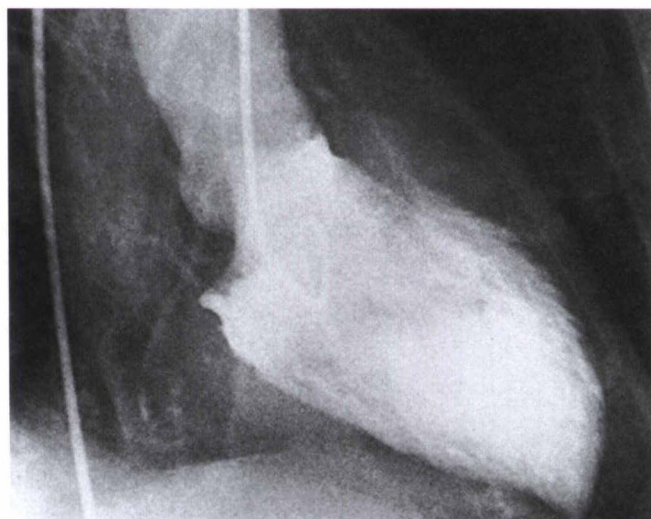


Fig. 26-111 Normal left ventriculogram during diastole.

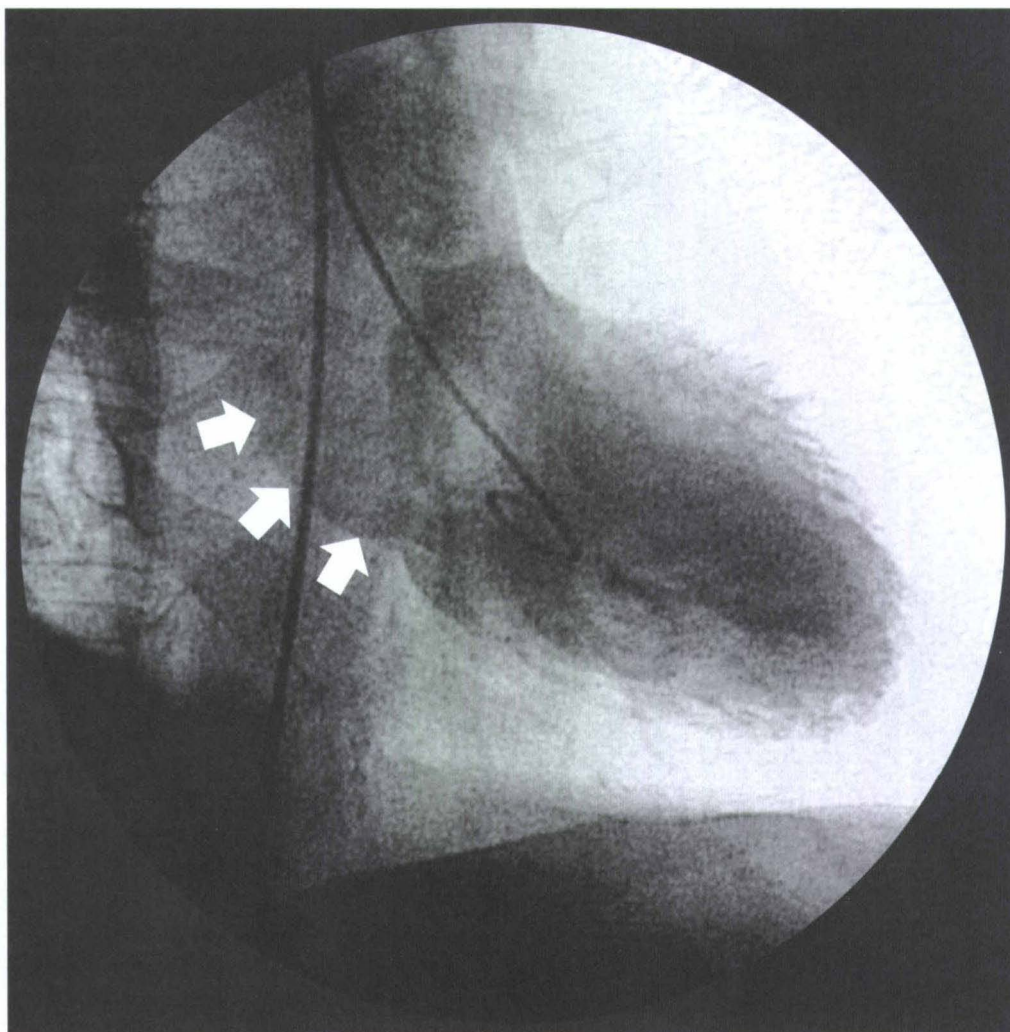


Fig. 26-112 Left ventriculogram demonstrating mitral valve regurgitation.

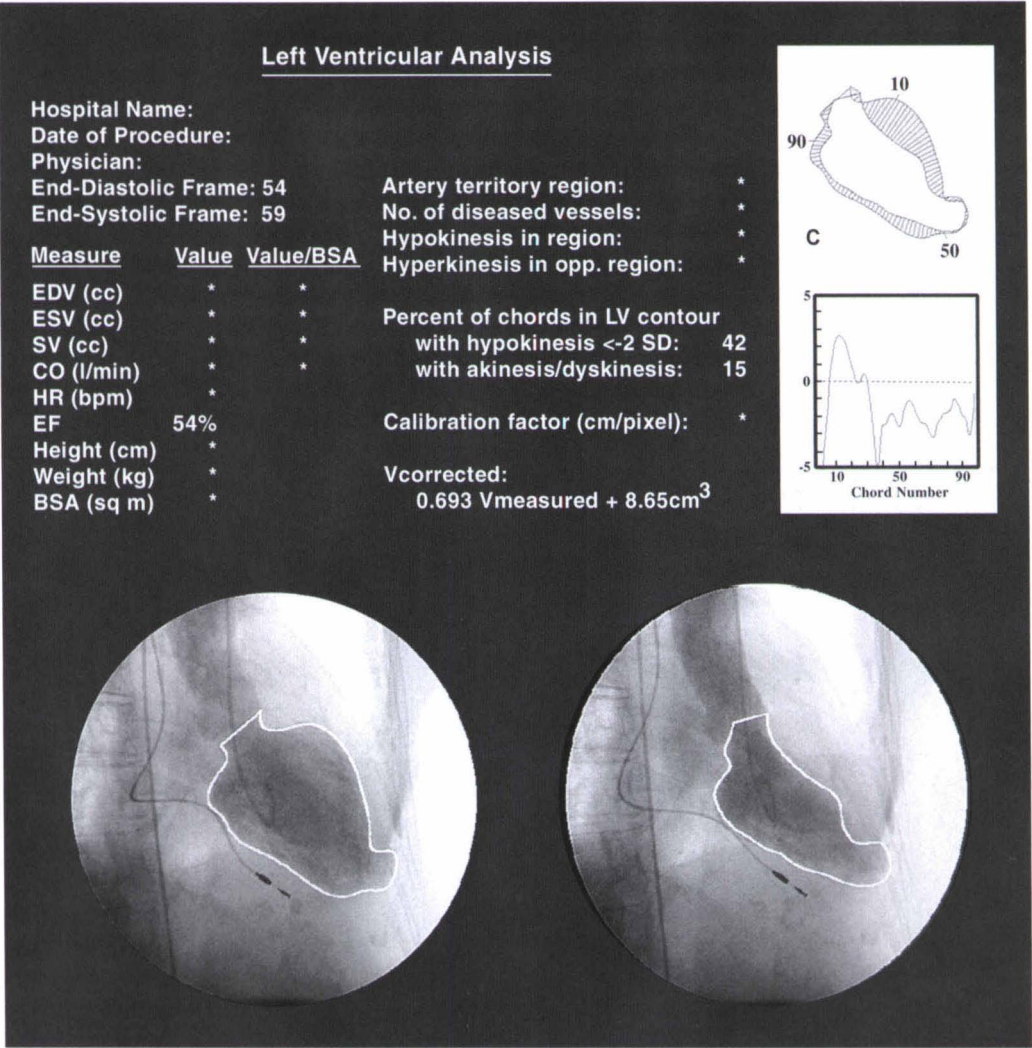
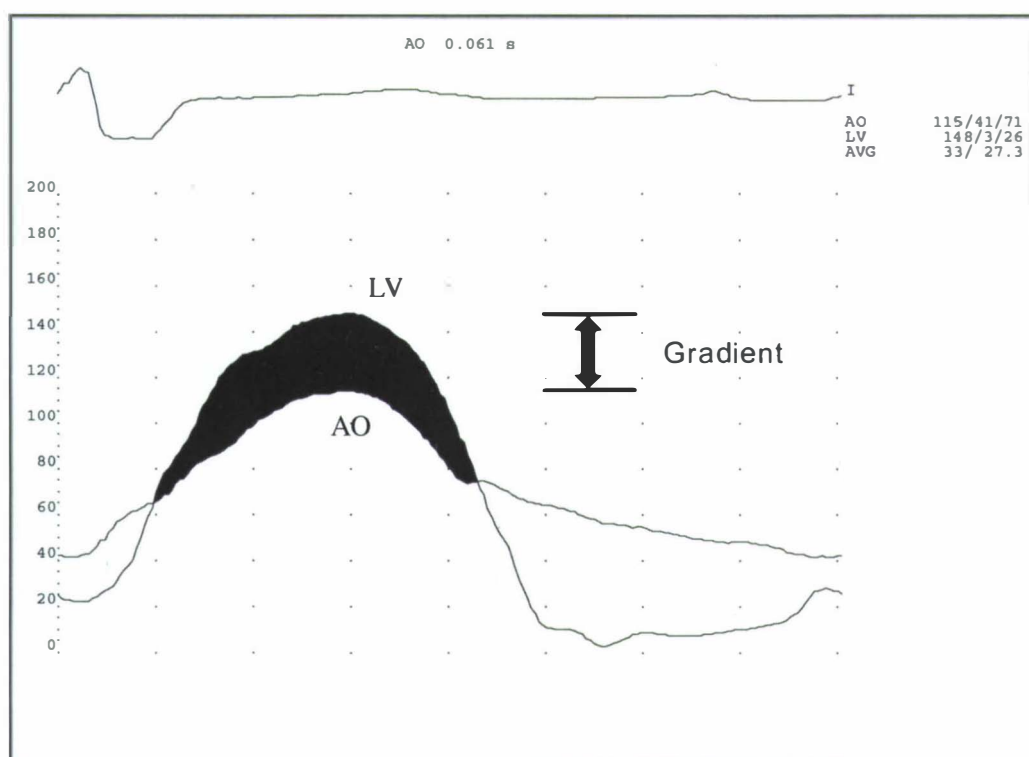
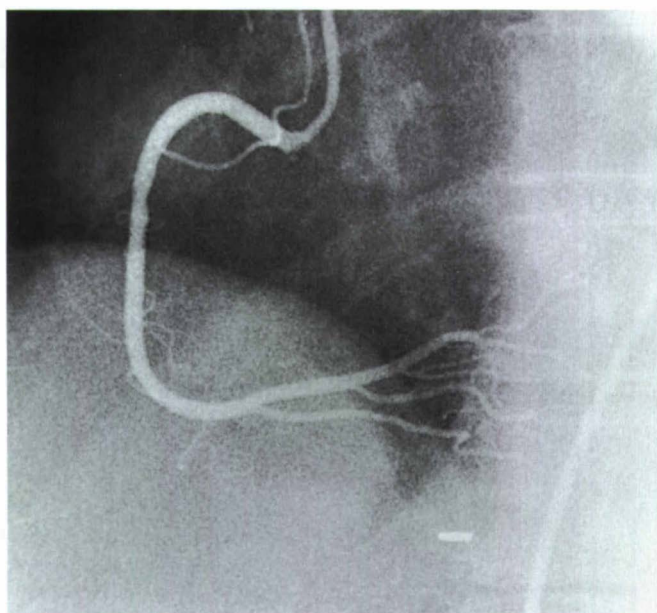


Fig. 26-113 Computerized planimetry for evaluation of left ventricular ejection fraction. **A**, Represents the diastolic phase of the heart's contraction. **B**, Represents the systolic phase of the heart's contraction. **C**, Represents a digital representation when the diastolic and systolic phases of the heart's contraction is superimposed.

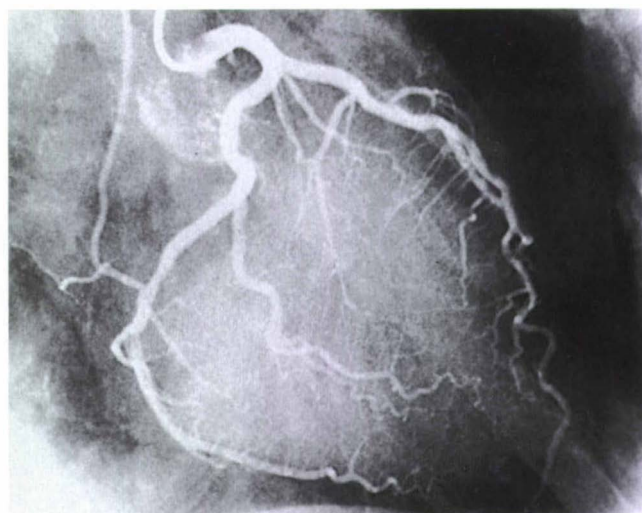




**Fig. 26-114** Aortic stenosis results when the aortic valve does not fully open during systole resulting in an increase in left ventricular pressure.



**Fig. 26-115** Normal right coronary artery.



**Fig. 26-116** Normal left coronary artery.

Because of the complexity of the anatomy involved, the variations in patient body habitus, and the presence of anomalies, a comprehensive guide for angiographic projections is difficult to establish. Instead, projections commonly used during coronary angiography are included in Table 26-6. The physician determines the projections that best demonstrate the artery of interest. Coronary arteriograms are obtained in nearly all catheterizations of the left side of the heart.

Catheterization of the right side of the heart is another commonly performed procedure. During right heart catheterization, a catheter is inserted into a vein in the groin or antecubital fossa and advanced to the vena cava, into the right atrium, across the tricuspid valve, to the right ventricle, and through the pulmonary valve to the pulmonary artery, until it is wedged distally in the pulmonary artery. Pressure measurements and oximetry are performed in each of the heart chambers as the catheter is advanced. The pressure measurements are used to determine the presence of such disorders as valvular heart disease, congestive heart failure, and certain cardiomyopathies. The oximetry data are used to determine the presence of an intracardiac shunt. Cineangiography is performed as appropriate.

Exercise hemodynamics are often required in the evaluation of valvular heart disease when symptoms of fatigue and dyspnea are present. In such cases, simultaneous catheterization and pressure measurements of the right and left heart are performed at rest and during peak exercise. Exercise often consists of pedaling a stationary bicycle, exercycle-type device—an ergometer—that is placed on top of the examination table. During simultaneous catheterization a catheter is placed in a vein (femoral or basilic) and an artery (femoral or brachial).

## Children

A primary indication for diagnostic catheterization studies in children is the evaluation and documentation of specific anatomy, hemodynamic data, and selected aspects of cardiac function associated with congenital heart defects. Methods and techniques used for catheterization of the pediatric heart vary depending on age, heart size, type and extent of defect, and other coincident pathophysiologic conditions.

Pediatric cardiac catheters are often introduced percutaneously into the femoral vein and in older children sometimes into the femoral artery. In very young patients, it may be possible to pass a catheter from the right atrium to the left atrium (thereby allowing access to the left side of the heart) through either a patent foramen ovale or a preexisting atrial septal defect. If the atrial septum is intact, temporary access to the left atrium may be obtained using a transseptal catheter system. With the transseptal catheter system, a long introducer and needle are used to puncture the right atrial septum of the heart to gain access to the left atrium if access cannot be attained as previously described.

**TABLE 26-6**

Common angiographic angles for specific coronary arteries

Coronary artery	Vessel segment	Projections*
Left coronary artery	Left main	PA or RAO 5 to 15 degrees
	Left anterior descending (LAD)	LAO 30 to 40 degrees, cranial 20 to 40 degrees
		RAO 5 to 15 degrees, cranial 15 to 45 degrees
		RAO 20 to 40 degrees, caudal 15 to 30 degrees
Right coronary artery	Circumflex	RAO 30 to 50 degrees
		Lateral
		RAO 20 to 40 degrees, caudal 15 to 30 degrees
	Middle right	LAO 40 to 55 degrees, caudal 15 to 30 degrees
		LAO 40 to 60 degrees
		LAO 20 to 40 degrees
	Posterior descending	RAO 20 to 40 degrees
		LAO 5 to 30 degrees, cranial 15 to 30 degrees

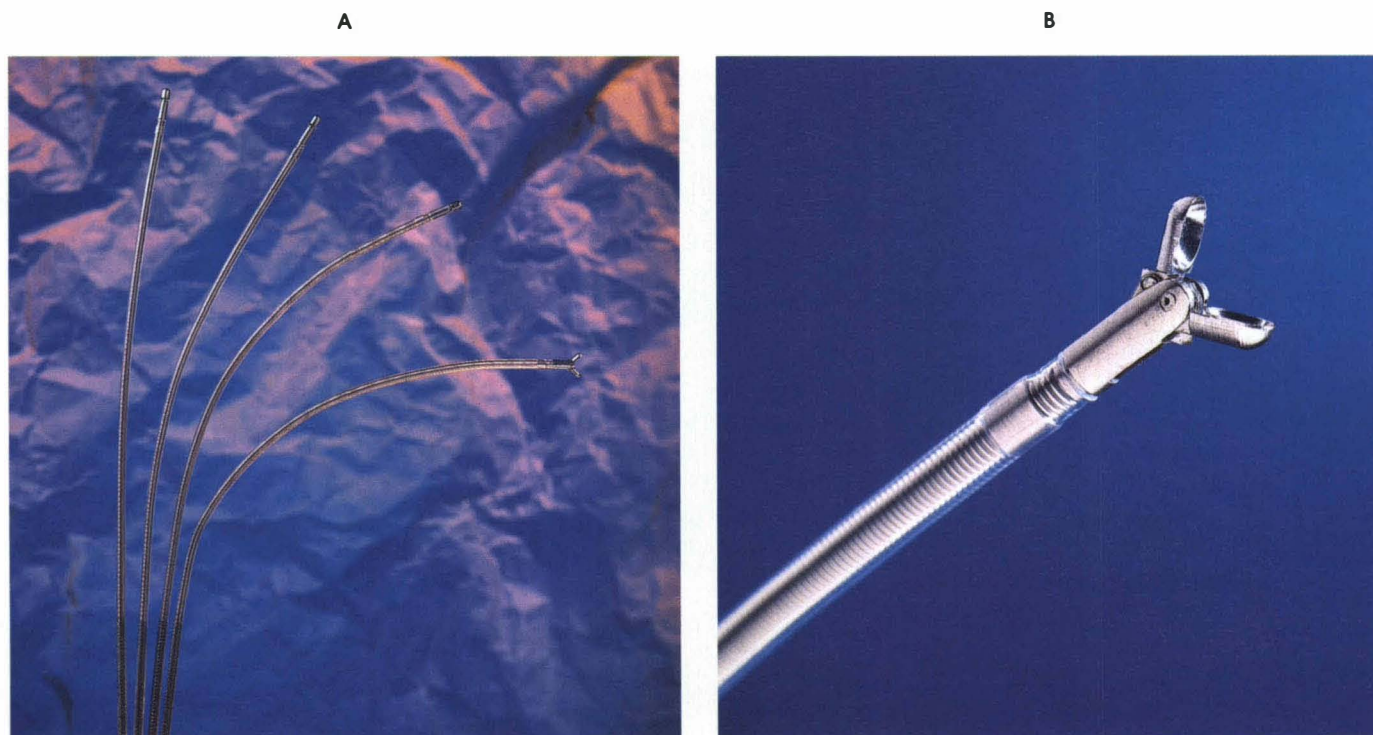
\*PA, Posteroanterior; RAO, right anterior oblique; LAO, left anterior oblique.

### ADVANCED DIAGNOSTIC STUDIES OF THE VASCULAR SYSTEM: ADULTS AND CHILDREN

An example of an advanced diagnostic study of the vascular system is endomyocardial biopsy, which is performed to provide a tissue sample for direct pathologic evaluation of cardiac muscle. A special biopsy catheter with a biptome tip (Fig. 26-117) is advanced under fluoroscopic

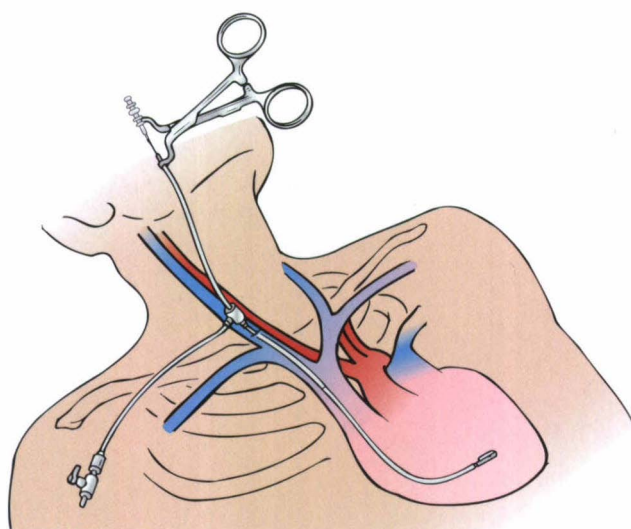
control from either the jugular or femoral vein to the right ventricle (Fig. 26-118). After the biptome is advanced into the ventricle, the jaws of the device are opened and the catheter is advanced to the ventricular septum. After the biptome is in contact with the septum, its jaws are closed and a gentle tugging motion is applied to retrieve the tissue sample. Several biopsy specimens are acquired in this

manner. The specimens are immediately fixed in either glutaraldehyde or buffered formalin before being sent for pathologic evaluation. Endomyocardial biopsy is frequently used to monitor cardiac transplantation patients for early signs of tissue rejection and to differentiate between various types of cardiomyopathies.



**Fig. 26-117** **A**, Standard biopsy catheters. **B**, Biptome catheter tip used for myocardial biopsy. The jaws on the tip close and take a "bite" from the inside of the heart muscle.

(Courtesy Cordis Corp., Miami, Fla.)



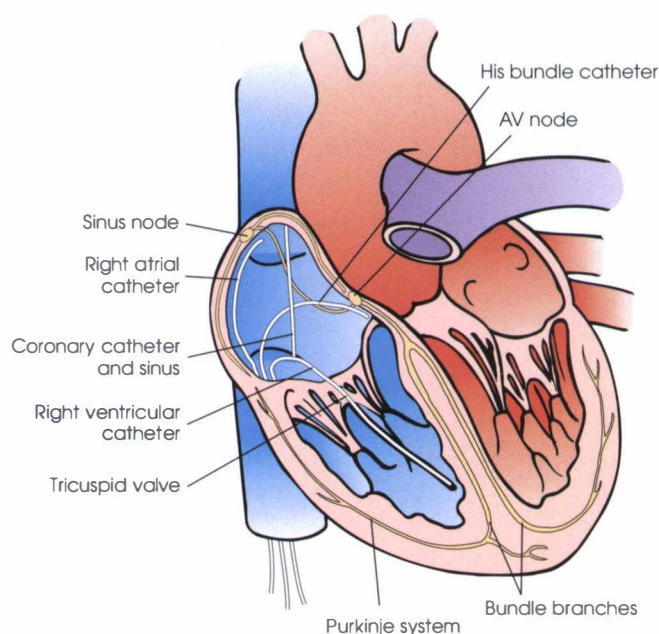
**Fig. 26-118** The biptome tip in the right ventricular apex, pointing toward the ventricular septum.



### ADVANCED DIAGNOSTIC STUDIES OF THE CONDUCTION SYSTEM: ADULTS AND CHILDREN

Electrophysiology studies involve the collection of sophisticated data to facilitate detailed mapping of the electrical conduction system within the heart. The procedures involve the placement of numerous multipolar catheters within the heart (Fig. 26-119). Electrophysiology studies are used to analyze the conduction system, induce and evaluate arrhythmias, and determine the effects of therapeutic measures in treating arrhythmias.

Electrode catheters are introduced into the femoral vein, internal jugular vein, or subclavian vein. Because several catheters are used, multiple access sites are needed. It is not uncommon to have three introducer sheaths placed within the same vein. The catheters consist of several insulated wires, each of which is attached to an electrode on the catheter tip that serves as an interface with the intracardiac surface. The arrangements of the electrodes on the catheter allow its dual function of recording the electrical signals of the heart (intracardiac electrograms) and pacing the heart. The pacemaker function is performed to introduce premature electrical impulses to determine possible arrhythmias. After characterization of the precise defect occurs, an appropriate course of therapy can be undertaken.



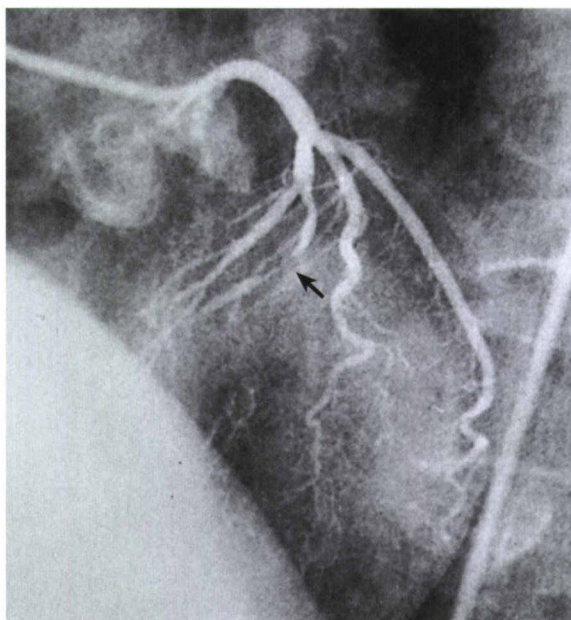
**Fig. 26-119** Catheter positions for routine electrophysiologic study. Multipolar catheters are positioned in the high right atrium near the sinus node, in the area of the atrioventricular apex, and in the coronary sinus.

## INTERVENTIONAL PROCEDURES OF THE VASCULAR SYSTEM

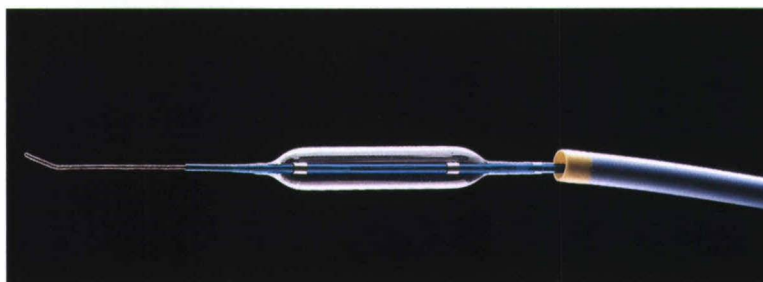
### Adults

Interventional cardiac catheterization techniques requiring special-purpose catheters have expanded significantly since the late 1970s. Percutaneous transluminal cardiac angioplasty is a technique that employs balloon dilation of a coronary artery stenosis to increase blood flow to the heart muscle. Gruentzig performed the first successful PTCA in 1977.

During PTCA, a specially designed guiding catheter is placed into the orifice of the stenotic coronary artery as determined by coronary angiography (Fig. 26-120). A steerable guide wire is inserted into the balloon catheter and advanced within the guiding catheter (Fig. 26-121). The guide wire is advanced across the stenotic area; it serves as a support platform so that the balloon catheter can be advanced and centered across the stenosis. Controlled and precise inflation of the balloon fractures and compresses the fatty deposits into the muscular

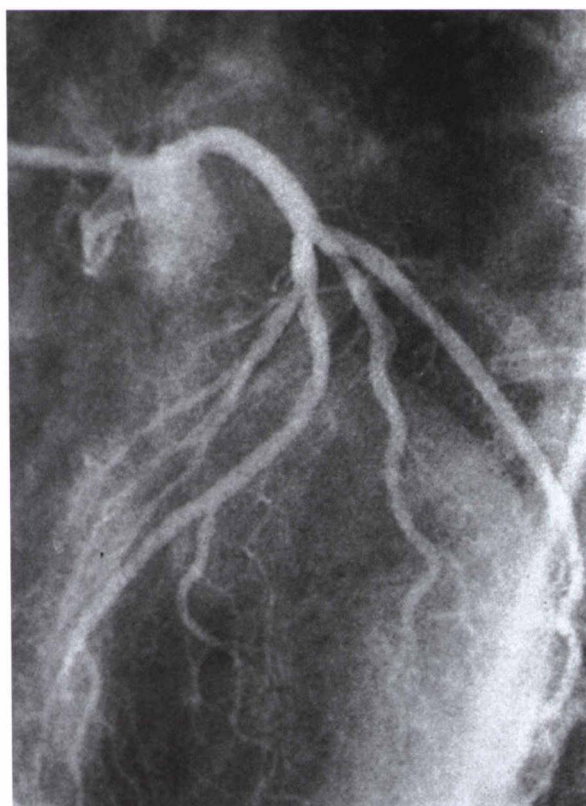


**Fig. 26-120** Stenotic coronary artery before PTCA. The arrow indicates the stenotic area, estimated at 95%, with minimum blood flow distal to the lesion.



**Fig. 26-121** Catheter system for PTCA. The three sections of the system are the outer guiding catheter (*right*), central balloon catheter (*middle*), and internal steerable guide wire (*left*).

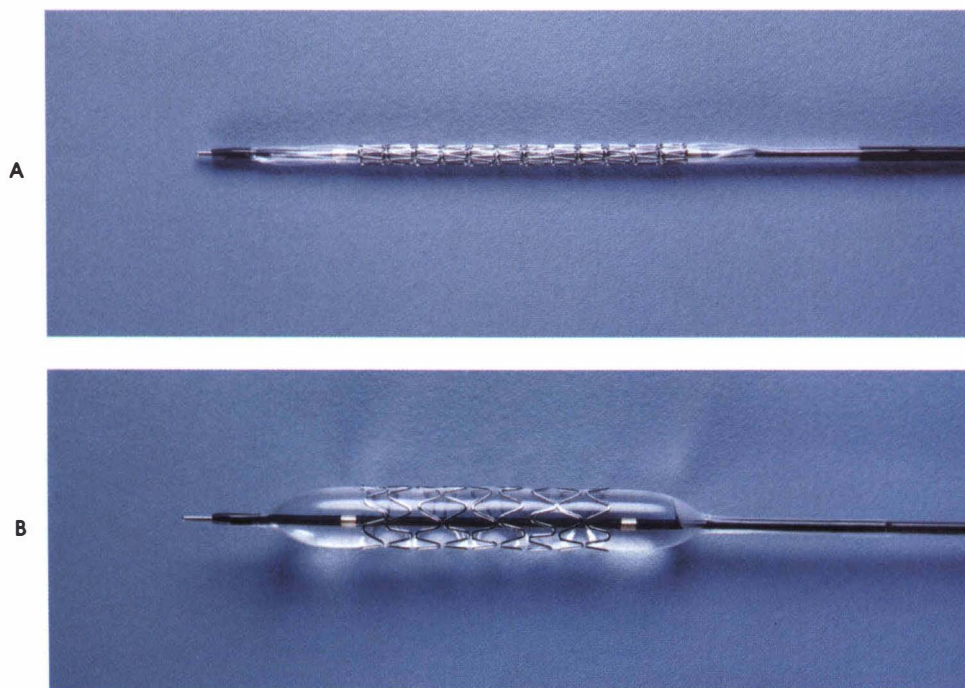
(Courtesy Cordis Corp., Miami, Fla.)



**Fig. 26-122** Coronary arteriogram after PTCA in the same patient as in Fig. 26-121. The blood flow is estimated to be 100%.

wall of the artery. This compression, in conjunction with the stretching of the external vessel diameter, is necessary for successful angioplasty. The balloon is deflated to allow rapid reperfusion of blood to the heart muscle. The inflation procedure, followed by arteriography, may be repeated several times until a satisfactory degree of patency is observed (Fig. 26-122). The limiting factor of PTCA is restenosis, which occurs in approximately 30% to 50% of the patients who undergo the procedure.

Another interventional procedure being performed more frequently on adult patients with coronary artery stenosis is the placement of an expandable intracoronary stent. The procedure is similar to PTCA and is performed in the same manner, except that a metallic stent is mounted on the PTCA balloon (Fig. 26-123). For optimum stent deployment, the stent is centered across the entire length of the stenosis. Deployment of the stent is achieved with the inflation and deflation of the PTCA balloon. After the stent is deployed, the angioplasty balloon is removed and a high-pressure balloon is advanced within the stent. Inflation of the high-pressure balloon is performed to embed the metallic struts of the stent in the walls of the blood vessel. Restenosis rates are lower in patients receiving intracoronary stents than in those who undergo conventional angioplasty.

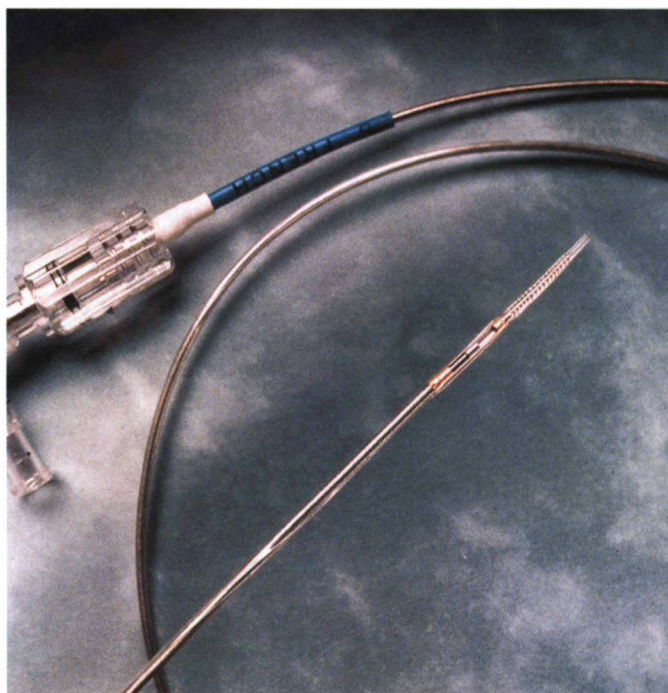


**Fig. 26-123** Balloon expandable intracoronary stent: **A**, Before stent balloon inflation; **B**, After stent balloon inflation.



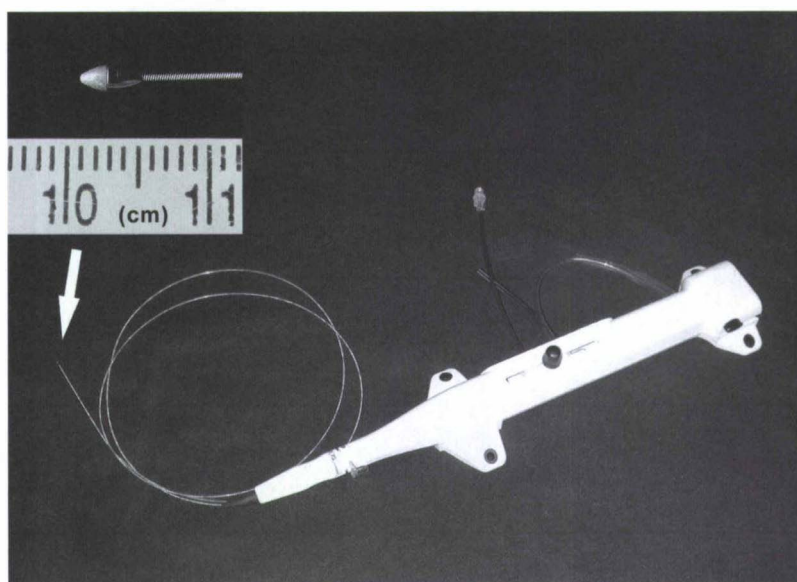
Atherectomy devices have also been used in the treatment of coronary artery disease. Unlike PTCA balloons, atherectomy devices remove the fatty deposit or thrombus material from within the artery (Fig. 26-124). The directional coronary atherectomy (DCA) procedure uses a specially designed cutting device to shave the plaque out of the lumen of the artery. As the cutting blade is advanced, the excised atheroma is pushed forward into the distal nose-cone collection chamber.

Another type of atherectomy device called a Rotablator has been indicated in the use of atherosclerotic coronary artery disease. Commonly referred to as PTCRA (percutaneous transluminal coronary rotational atherectomy), it can be used in conjunction with PTCA and/or stenting. The tip of the catheter (1.25 to 2.5 mm in diameter) resembles a football and is embedded with microscopic diamond particles on the front half and is rotated on a special torque guidewire between 160,000 to 200,000 rpm (Fig. 26-125).



**Fig. 26-124** Coronary atherectomy device used during directional coronary atherectomy. The balloon on the inferior aspect of the cutting device is inflated inside the coronary artery; plaque is forced into the opening, then shaved off and collected in the tip.

(Courtesy Guidant Vascular Intervention, Santa Clara, Calif.)

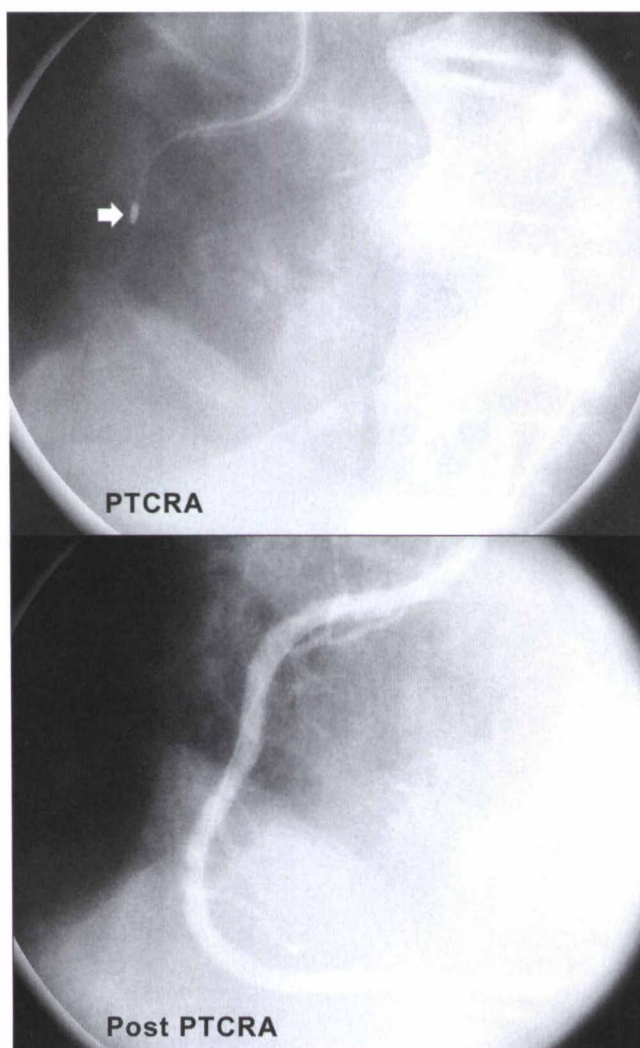


**Fig. 26-125** Rotational atherectomy catheter with advancer unit. Insert shows "football" shaped burr.

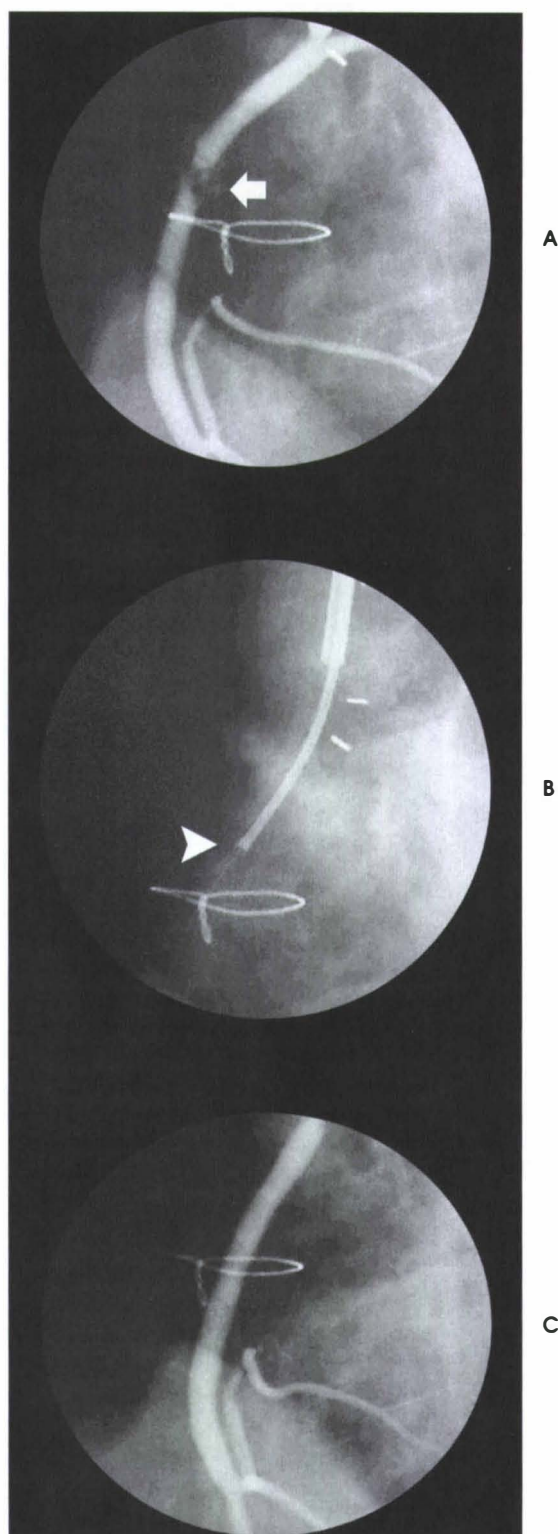
Standard angioplasty catheter positioning techniques are utilized to position a guidewire distal to the targeted lesion. A rotational atherectomy burr size is selected and advanced over the special torque guidewire just proximal to the lesion. At this point, the burr is activated and the plaque is pulverized and reduced to the size of a blood cell. The pulverized plaque is removed by the reticuloendothelial system. After an adequate amount of plaque is cleared, standard PTCA and/or stenting techniques are employed to maintain artery patency (Fig. 26-126). PTCRA has proven to be a benefit in the treatment of in-stent restenosis when compared to PTCA alone.

The transluminal extraction catheter (TEC) atherectomy procedure uses a cutting device that consists of a pair of stainless-steel cutting blades arranged in a conical configuration. The central lumen of the cutting device is attached to a vacuum bottle that aspirates thrombus and atheromatous tissue as the cutting blade is advanced through the lesion. Atherectomy procedures generally require adjunctive PTCA or intracoronary stent placement to achieve an optimum angiographic result (Fig. 26-127).

While coronary angiography remains the "gold standard" for the diagnosis of coronary artery disease, *intravascular ultrasound* (IVUS) offers to provide further diagnostic and interventional information of which cannot be appreciated by angiography alone. Intravascular ultrasound allows a full 360° circumference visualization of the vessel wall and permits information regarding vascular pathology, longitudinal and volumetric measurements, and facilitates guidance of catheter-based interventions. The intervention associated potentials of intravascular ultrasound is the ability to optimize the type and size of device (i.e., PTCA/stent vs. Rotablator, atherectomy) being used.



**Fig. 26-126** Percutaneous transluminal rotational atherectomy (PTCRA). Arrow pointing to burr of catheter. Post PTCRA shows a widely patent right coronary artery.



**Fig. 26-127** Transluminal extraction catheter (TEC). **A**, Pre-TEC, arrow pointing to area of thrombus formation; **B**, TEC catheter being advanced adjacent to area of thrombus, arrowhead pointing to tip of TEC catheter; **C**, post TEC showing patent right coronary artery.



PTCA and/or stent interventions by far remain the bulk of the coronary interventions being performed today. Of major concern are dissection at the proximal and distal ends of the stent and complete apposition of the stent against the vessel wall (Fig. 26-128). A large observational study following angiography guided stent deployment revealed an average residual plaque area of 51% comparing minimum stent diameter to the normal artery. Additional balloon inflations resulted in a final average residual stenosis of 34%, even though the final angiographic percentage stenosis was negative ( $-0.7\%$ ).<sup>1</sup>

<sup>1</sup>Colombo A, Hall P, Nakamura S, et al: Intracoronary stenting without anticoagulation accomplished with intravascular ultrasound guidance, *Circulation* 91:1676, 1995.

Components consist of the ultrasound unit, recording device (usually a VCR), printer, transducer, pullback device, and catheter (Fig. 26-129). The intravascular catheters being used today utilize 20 to 40 MHz silicon piezoelectric crystals and ranges in size from 5 Fr on the proximal end of the catheter to 2.9 Fr at the distal end (Fig. 26-130). During the procedure, the intravascular ultrasound catheter is advanced over the guidewire that was previously placed within the artery being imaged. The intravascular ultrasound catheter is advanced distal to the targeted lesion and

at which time the transducer and recording device is turned on. Slowly, the catheter is withdrawn using the pullback device to maintain a consistent withdrawal of the catheter and help to ascertain the length of the targeted lesion. A recording device such as a VCR is used to store the acquired dynamic images and cardiologist's audio dictation during IVUS acquisition. Documentation of IVUS catheter position can be obtained with angiography. This allows the cardiologist to later review, take measurements, and print images from the videotape.

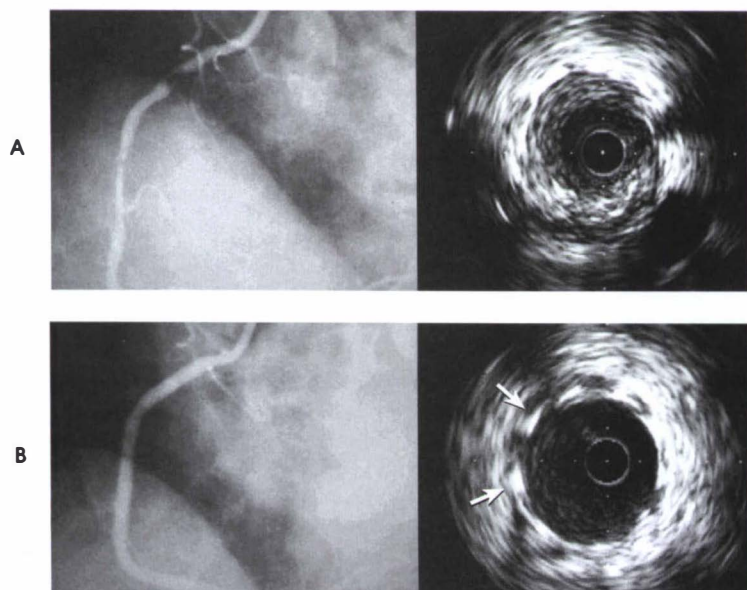


Fig. 26-128 Intravascular ultrasound images shown on right correlated with angiography images on left. Arrows in B shows the echogenicity of the stent struts during IVUS.

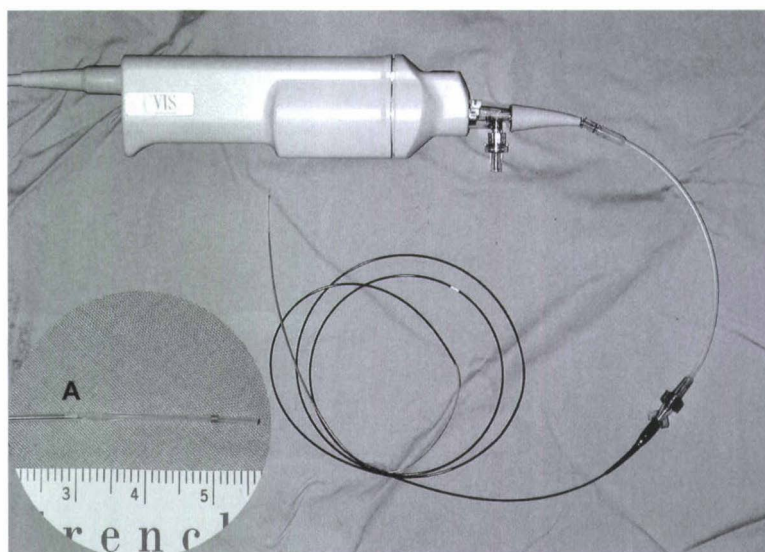


Fig. 26-129 Intravascular ultrasound (IVUS) unit. Shown here are the keyboard, monitor, VCR, and printer.

At present, intravascular ultrasound remains an integral part of coronary interventions being performed. With the advanced in stent designs, brachytherapy, local drug delivery, and future technologies, intravascular ultrasound will remain a vital source for information in improving the outcomes of percutaneous coronary interventions. Equipment under investigation combines an imaging transducer with an interventional device, permitting guidance during the interventional procedure. The clinical use of intravascular ultrasound imaging and other improved computerized image enhancements should allow for more precise data collection and more tailored methods of determining the interventional method to use in treating coronary artery disease.

Because of the risks associated with mechanical interventions of the vascular system, open-heart surgical facilities must be immediately available. Coronary occlusion, for example, is a major complication requiring emergency surgery in patients undergoing catheter-based mechanical interventions.

Interventional pharmacologic procedures in adults consist of the therapeutic administration of medications during cardiac catheterization. An example is the intracoronary infusion of urokinase, which is a thrombolytic agent used in the early hours of an acute MI in an effort to modify its course. Estimates indicate that thrombotic coronary artery occlusion is present in 75% to 85% of patients with acute MI. If reperfusion of the ischemic myocardium is effective, scarring is reduced. Reperfusion in the early stages of MI offers greater potential for heart muscle salvage.



**Fig. 26-130** Intravascular ultrasound (IVUS) catheter and transducer. **A**, Inset shows tip of transducer.

### Children

A number of congenital cardiac defects in children are amenable to interventional procedures performed in the catheterization laboratory. As with PTCA procedures, cardiovascular surgical support services must be readily available.

When successful, certain pediatric interventional procedures negate the need for surgical correction of defects. However, some procedures are performed for palliative purposes to allow the child to grow to a size and weight at which subsequent open-heart surgery is feasible.

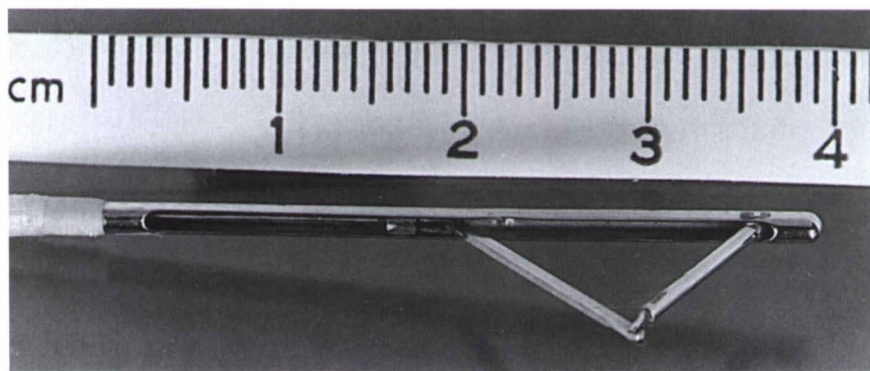
One such technique, *balloon septostomy*, may be used to enlarge a patent foramen ovale or preexisting *atrial septal defect*. Enlargement of the opening enhances the mixing of right and left atrial blood, resulting in an improved level of systemic arterial oxygenation. Transposition of the great arteries is a condition for which atrial septostomy is performed.

Balloon septostomy requires a catheter similar to the type used in PTCA. The balloon is passed through the atrial septal opening into the left atrium, inflated with contrast medium, and then snapped back through the septal orifice. This causes the septum to tear. Often the technique must be repeated until the septal opening is sufficiently enlarged to allow the desired level of blood mixing as documented by oximetry, intracardiac pressures, and angiography.

If the atrial septum does not contain a preexisting opening, an artificial defect can be created. A transseptal system approach is employed, and a special catheter containing an internal folding knifelike blade is advanced into the left atrium (Fig. 26-131). After the catheter is inside the left atrium, the blade is advanced out of its protective outer housing and pulled back to the right atrium, creating an incision in the septal wall. This technique may be repeated. A balloon septostomy is then performed to widen the new opening, and the condition of the patient is monitored by oximetry, blood pressures, and angiography.

A patent ductus arteriosus is sometimes evident in the newborn. In utero the pulmonary artery shunts its blood flow into the aorta through the ductus arteriosus, which normally closes after birth. Patent ductus arteriosus occurs when this channel fails to close spontaneously. In some instances, closure can be induced with medication. If this measure is unsuccessful and the residual shunt is deemed significant, surgical closure (ligation) of the vessel is appropriate.

For some patients, occlusion of a patent ductus arteriosus can be accomplished in the catheterization laboratory. A catheter containing an occlusion device, such as an umbrella, is advanced to the ductus. After the position of the lesion is confirmed by angiography, the occluder is released. Subsequent clotting and fibrous infiltration permanently stop the flow and subsequent mixing of blood.

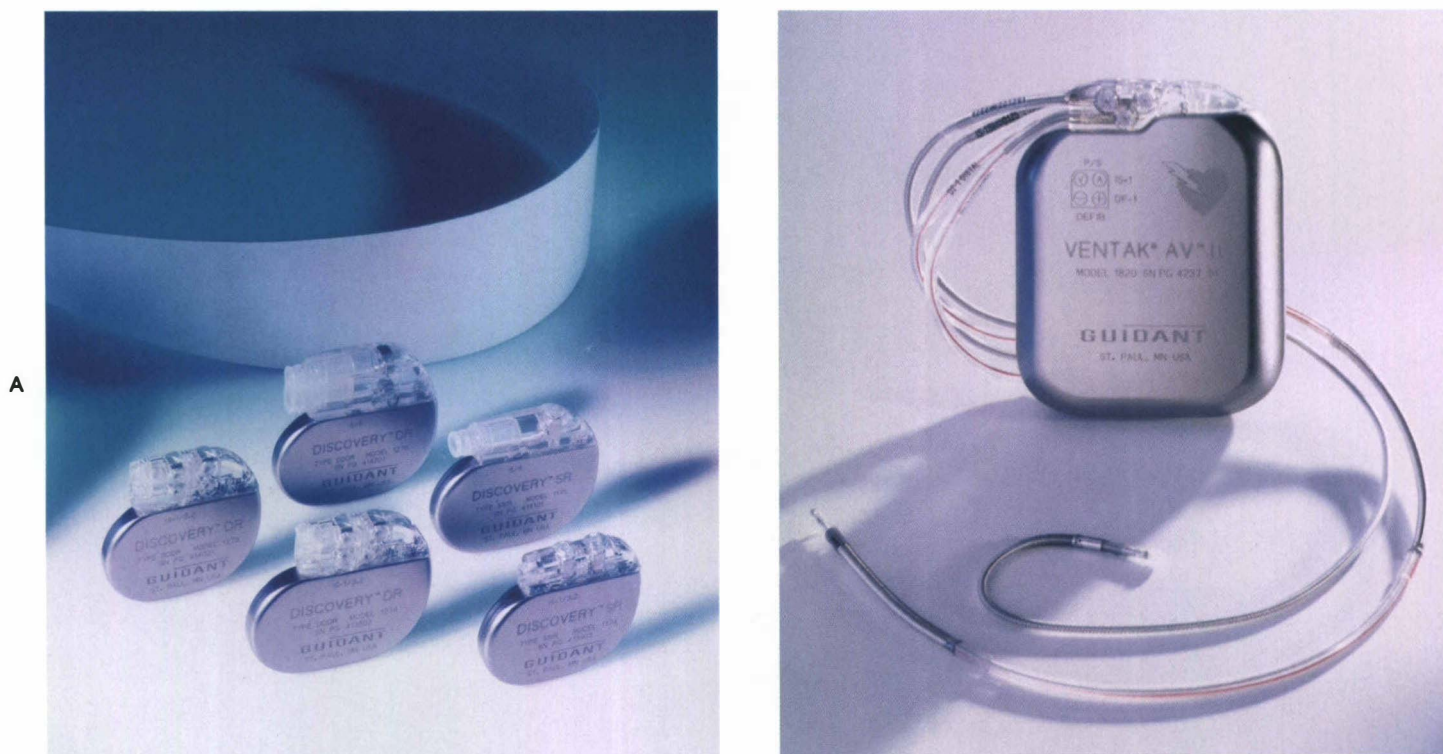


**Fig. 26-131** Blade on catheter tip used to incise septal walls in pediatric interventional procedures.



### INTERVENTIONAL PROCEDURES OF THE CONDUCTION SYSTEM: ADULTS AND CHILDREN

Permanent implantation of an antiarrhythmic device is a manipulative procedure that is being performed with greater frequency in cardiac catheterization laboratories, rather than in operating rooms (Fig. 26-132). Antiarrhythmic devices include pacemakers for patients with bradyarrhythmias and/or disease of the electrical conduction system of the heart and implantable cardioverter defibrillators (ICDs) for patients with lethal ventricular tachyarrhythmias originating from the bottom of the heart.



**Fig. 26-132** **A**, Single-chamber and dual-chamber pacemakers. **B**, Implantable cardioverter defibrillator.

(Courtesy Guidant Corp., Cardiac Pacemakers, Inc., St. Paul, Minn.)

Pacemaker implantation can be successfully performed under local anesthesia in selected adult and pediatric patients. ICD implantation requires conscious sedation or general anesthesia because of the type of testing required at the time of implantation. Insertion of either a pacemaker or an ICD involves puncturing the subclavian or cephalic vein and introducing leads (electrically insulated wires with distal electrodes). The leads are manipulated so that their tips are in direct contact with the right ventricular or right atrial endocardium, or both. The leads are then tested for stimulation and sensing properties to ascertain proper functioning before they are attached to the pulse generator. During ICD implantation, defibrillation threshold testing is performed to determine the amount of energy required to defibrillate a patient from ventricular tachycardia or fibrillation. After testing is completed, the proximal end of the lead(s) is then attached to a battery pack (pacemaker or ICD) and implanted in a subcutaneous or subpectoral pocket created in the thorax (Fig. 26-133). Current pacemakers have a longevity of 5 to 10 years, and ICDs have a longevity of 6 to 8 years.

Another interventional procedure being performed to treat disorders of the conduction system in the cardiac catheterization laboratory is radiofrequency (RF) ablation. Several different arrhythmias previously treated with ICD implantation or drug therapy can now be treated with RF ablation. The procedure is normally performed at the time of the diagnostic electrophysiology study if an underlying mechanism or arrhythmogenic focus is identified.

RF ablation is achieved by delivering a low-voltage, high frequency alternating current directly to the endocardial tissue through a specially designed ablation catheter. The current desiccates the underlying abnormal myocardial conduction tissue and creates a small, discrete burn lesion. Localized RF lesions create areas of tissue necrosis and scar, subsequently destroying the arrhythmogenic focus. Several RF lesions may be necessary to eliminate the abnormal conduction circuit.

Follow-up electrophysiologic testing is performed to document the resolution of the arrhythmia. RF ablation of the atrioventricular (AV) node and pacemaker insertion are fast becoming the preferred treatment for chronic atrial fibrillation with rapid irregular responses. The AV junction is destroyed intentionally; consequently the rapid irregular electrical impulses from the atrium are not conducted into the ventricle. A pacemaker is then implanted, and a more consistent, regular heart rate is achieved.

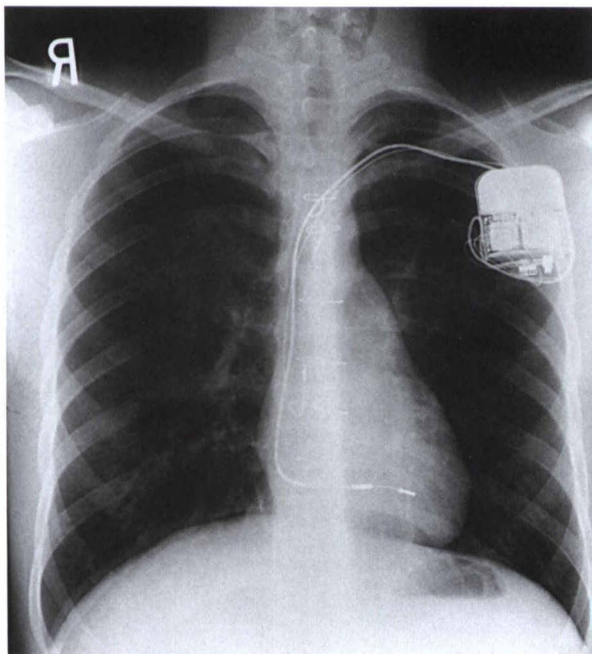


Fig. 26-133 Chest radiograph of a patient with a permanent pacemaker implanted. Note the pacemaker location in the superior and anterior chest wall, with the distal leads located in both the right ventricle and right atrium of the heart.

## Postcatheterization Care

When the catheterization procedure is completed, all catheters are removed. If a cut-down approach was used, the arteriotomy or venotomy is repaired as appropriate. If a percutaneous approach was used, pressure is placed on the puncture site until the bleeding is controlled. Wound sites are cleaned and dressed to minimize the risk of infection. Elastic dressings are often used to encourage hemostasis.

Post catheterization medications are prescribed by the physician. The puncture site must be observed for hemorrhage or hematoma, and the status of the distal pulse is recorded on the protocol record before the patient leaves the catheterization laboratory. Vital signs should be monitored regularly for at least 24 hours after the catheterization. The ingestion of fluids should be encouraged, and pain medication may be indicated.

Cardiac catheterization may also be performed on an outpatient or same-day treatment basis. The patient is monitored for 4 to 8 hours in a recovery area and then allowed to go home. Instructions for home-care recovery procedures are usually given to the patient or a family member before the patient leaves the recovery area.

## Cardiac Catheterization Trends

### VASCULAR BRACHYTHERAPY

*Vascular brachytherapy*, also termed vascular radiotherapy is a technique where radiation is delivered to an area of a previously stented artery utilizing endovascular techniques. Current radiation sources under consideration are gamma- and beta-emitting sources. The studies completed thus far have shown very encouraging results.

The renarrowing (*restenosis*) of the coronary artery in the months following a successful PTCA and/or stenting remains the major limitation to percutaneous coronary revascularization. Studies have shown that following percutaneous coronary revascularization, a complex process whereby remodeling of the angioplasty and/or stented portion of the artery takes place. One such remodeling process is the growth of a new lining of cells over the revascularized site. When this new lining of cells occurs rapidly, the term neointimal hyperplasia is used. Neointimal hyperplasia is the result of smooth muscle hyperplasia and matrix proliferation secondary to the revascularization process. Neointimal hyperplasia remains the biggest factor in restenosis after intervention.

An alternative approach to delivered vascular brachytherapy involves the use of stents impregnated with beta isotopes. The isotope slowly decays over a period of 6 months. Studies have shown that in-stent restenosis is minimized with radioactive stents. However, stenoses along the edges of the stent have occurred. Further investigation regarding the type of isotope, radiation dosage, and the effects of radiation on the arterial wall and surrounding tissues are being studied.

### DRUG ELUTING STENT

As previously discussed, restenosis of the coronary artery after revascularization is the major factor in failed long-term outcomes. Local drug delivery systems are currently under clinical investigations. The goal is to reduce or inhibit restenosis that occurs after a revascularization procedure. Currently, companies are working with drugs that are chemically bound to a stent that over time releases a small amount of the drug that will inhibit restenosis. The various drugs under investigation reduce restenosis by limiting the proliferation of smooth muscle cells and/or reducing the rate at which this occurs. The prevention of restenosis after revascularization remains to be proven. The short-term data has proven to be quite positive. Long-term clinical data from large randomized trials are being investigated.

### MAGNETIC RESONANCE IMAGING

Techniques and methods for cardiac catheterization continue to be developed and refined. Angiographic imaging and recording devices are becoming even more sophisticated and therefore yielding ever-greater resolution and detail. Magnetic resonance imaging (see Chapter 36) of the cardiovascular system is now a well-recognized investigational technique. Magnetic resonance coronary arteriography is now able to reliably assess anomalous coronary artery anatomy and to identify the presence of calcification in the coronary arteries and bypass grafts.



## ELECTRON BEAM COMPUTED TOMOGRAPHY

Recently, an area receiving lots of recognition in the study of coronary artery disease is the use electron beam tomography (EBT) imaging. Many manufacturers are working on similar imaging equipment by using ultra-fast CT scanning coupled with software reconstruction algorithms to accomplish the goal of non-invasive coronary angiography (see Chapter 33). EBT can detect heart disease at its earliest and most treatable stages by measuring the amount of coronary calcium. The coronary calcium score provides a good indication of how blocked the artery is.

The patient lies on a table similar to a conventional CT scan. The significant difference between a conventional CT scanner and EBT is the exposure time. Exposure times for the EBT is around 100 milliseconds. This typically results in about 30 to 40 scans and the ability to scan the entire heart in a single breath hold.

Another technique using the EBT is with the injection of contrast media intravenously. The term *Electron Beam Angiography (EBA)* is a simple and non-invasive technique utilizing an intravenous venous injection of contrast media. EBA is effective for visualization of the heart, great vessels, carotid arteries, and peripheral vasculature. EBA has shown to demonstrate the coronary arteries with a high degree of accuracy when compared to conventional angiography.

Many experts feel that the greatest area for growth in the field of cardiac catheterization is in interventional procedures. Despite the use of such techniques as PTCA, intracoronary stenting, and atherectomy in coronary artery disease, restenosis continues to be prevalent and of major concern. The majority of the research in interventional procedures is geared toward finding a technique to prevent or greatly limit restenosis after an intervention. Procedures classified as experimental or investigational in the late 1980s are now being performed regularly. Existing and new interventional procedures should continue to provide patients with viable, relatively low-risk, financially reasonable alternatives to open-heart surgery. Current trends indicate that the number and variety of outpatient cardiac catheterizations will continue to increase. The equipment used and procedures performed in the cardiac catheterization laboratories of the future are likely to be significantly different from those associated with existing facilities and techniques employed today. However, despite changes in cardiovascular technology and medical techniques, cardiac catheterization laboratories will continue to provide essential patient care services necessary for the diagnosis and treatment of a vast number of cardiovascular-related diseases.

## Definition of Terms

**afferent lymph vessel** Vessel carrying lymph toward a lymph vessel.

**anastomose** Join.

**aneurysm** Sac formed by local enlargement of a weakened artery wall.

**angina pectoris** Severe form of chest pain and constriction near the heart; usually caused by a decrease in the blood supply to cardiac tissue; most often associated with stenosis of a coronary artery as a result of atherosclerotic accumulations or spasm. The pain generally lasts for a few minutes and is more likely to occur after stress, exercise, or other activity resulting in increased heart rate.

**angiography** Radiographic demonstration of blood vessels after the introduction of a contrast medium.

**anomaly** Variation from the normal pattern.

**aortic dissection** Tear in the inner lining of the aortic wall that allows blood to enter and track along the muscular coat.

**aortography** Radiographic examination of the aorta.

**arrhythmia** Variation from normal heart rhythm.

**arrhythmogenic** Producing an arrhythmia.

**arteriography** Radiologic examination of arteries after the injection of a radiopaque contrast medium.

**arteriole** Very small arterial vessel.

**arteriosclerotic** Indicative of a general pathologic condition characterized by thickening and hardening of arterial walls, leading to general loss of elasticity.

**arteriotomy** Surgical opening of an artery.

**arteriovenous malformation** Abnormal anastomosis or communication between an artery and a vein.

**artery** Large blood vessel carrying blood away from the heart.

**atherectomy** Excision of atherosclerotic plaque.

**atheromatous** Characteristic of degenerative change in the inner lining of arteries caused by the deposition of fatty tissue and subsequent thickening of arterial walls that occurs in atherosclerosis.

**atherosclerosis** Condition in which fibrous and fatty deposits on the luminal wall of an artery may cause obstruction of the vessel.

**atrium** One of the two upper chambers of the heart.

**bifurcation** Place where a structure divides into two branches.

**blood vascular system** Vascular system comprising of arteries, capillaries and veins which convey blood.

**biplane** Two x-ray exposure planes 90 degrees from another, usually frontal and lateral.

**bradyarrhythmia** Irregular heart rhythm in conjunction with bradycardia.

**bradycardia** Any heart rhythm with an average heart rate of less than 60 beats per minute.

**capillary** Tiny blood vessel through which blood and tissue cells exchange substances.

**cardiac output** Amount of blood pumped from the heart per given unit of time; can be calculated by multiplying stroke volume (amount of blood in milliliters ejected from the left ventricle during each heartbeat) by heart rate (number of heartbeats per minute). A normal, resting adult with a stroke volume of 70 ml and a heart rate of 72 beats per minute has a cardiac output of approximately 5.0 L per minute.

**cardiomyopathies** Relatively serious group of heart diseases typically characterized by enlargement of the myocardial layer of the left ventricle and resulting in decreased cardiac output; hypertrophic cardiomyopathy is a condition often studied in the catheterization laboratory.

**cardiovascular and interventional technologist** Technologists specializing in angiographic and interventional procedures.

**cerebral angiography** Imaging of vascular system of the brain.

**cineangiography** High-speed, 35-mm motion picture film recording of a fluoroscopic image of structures containing radiographic contrast medium.

**cinefluorography** Same as cineradiography; the production of a motion picture record of successive images on a fluoroscopic screen.

**claudication** Cramping of the leg muscles after physical exertion because of chronically inadequate blood supply.

**coagulopathy** Any disorder that affects the blood-clotting mechanism.

**collateral** Secondary or accessory.

**diastole** Relaxed phase of the atria or ventricles of the heart during which blood enters the chambers; not in the cardiac cycle at which the heart is not contracting (at rest).

**directional coronary atherectomy (DCA)** Excision of atheroma through a percutaneous transcatheter approach using a rotating cutting device supported by a balloon positioned on the back of the catheter.

**dyspnea** Labored breathing.

**efferent lymph vessel** Vessel carrying lymph away from a node.

**ejection fraction** Measurements of ventricular contractility expressed as the percentage of blood pumped out of the left ventricle during contraction; can be estimated by evaluating the left ventriculogram; normal range is between 57% and 73%, with an average of 65%. A low ejection fraction indicates failure of the left ventricle to pump effectively.

**embolus** Foreign material, often thrombus, that detaches and moves freely in the bloodstream.

**endocardium** Interior lining of heart chambers.

**ergometer** Device used to imitate the muscular, metabolic, and respiratory effects of exercise.

**epicardium** Exterior layer of heart wall.

**extravasation** Escape of fluid from a vessel into the surrounding tissue.

**fibrillation** Involuntary, chaotic muscular contractions resulting from spontaneous activation of single muscle cells or muscle fibers.

**film changer** Device that transports radiographic films into and out of the exposure field for serial imaging.

**French size** A measurement of catheter sizes, 1 French = 0.33 mm.

**guidewire** Tightly wound metallic wire over which angiographic catheters are placed.

**hematoma** Collection of extravasated blood in an organ or a tissue space.

**hemodynamics** Study of factors involved in circulation of blood. Hemodynamic data typically collected during heart catheterization are cardiac output and intracardiac pressures.

**hemostasis** Stopping of blood flow in a hemorrhage.

**hydronephrosis** Distention of the pelvis and calices of the kidney with urine, caused by ureteral obstruction.

**iatrogenic** Caused by a therapeutic or diagnostic procedure.

**innominate or brachiocephalic artery** The first major artery of the aortic arch supplying the cerebral circulation.

**in-stent restenosis** Renarrowing of an artery inside of a previously placed stent.

**interventricular septal integrity** Continuity of the membranous partition that separates the right and left ventricles of the heart.

**intervention** Therapeutic modality—mechanical or pharmacologic—used to modify the course of a disease process.

**interventional** Improving a condition; therapeutic.

**intracoronary stent** Metallic device placed within a coronary artery across a region of stenosis.

**introducer sheath** Plastic tubing placed within the vasculature through which other catheters may be passed.

**ischemic** Indicative of a local decrease of blood supply to myocardial tissue associated with temporary obstruction of a coronary vessel, typically as a result of thrombus (blood clot).

**lesion** Injury or other damaging change to an organ or tissue.

**lymph** Body fluid circulated by the lymphatic vessels and filtered by the lymph nodes.

**lymph vessels** See afferent and/or efferent lymph vessel.

**lymphadenography** Radiographic study of the lymph nodes.

**lymphangiography** Radiographic study of the lymph vessels.

**lymphography** Radiographic evaluation of the lymphatic channels and lymph nodes.

**mandrel** Inner metallic core of a spiral wound guidewire.

**meninges** Three membranes that envelop the brain and spinal cord.

**myocardium** Muscular heart wall.

**myocardial infarction (MI)** Acute ischemic episode resulting in myocardial damage and pain; commonly referred to as a heart attack.



**nephrectomy** Surgical removal of the kidney.

**nephrostomy** Surgical opening into the kidney's collecting system.

**nephrotoxic** Chemically damaging to the kidney cells.

**neointimal hyperplasia** Hyperproliferation of smooth muscle cells and extracellular matrix secondary to revascularization.

**nonocclusive** Not completely closed or shut; allowing blood flow.

**occlusion** Obstruction or closure of a vessel, such as a coronary vessel, as a result of foreign material, thrombus, or spasm.

**oximetry** Measurement of oxygen saturation in blood.

**oxygen saturation** Amount of oxygen bound to hemoglobin in blood, expressed as a percentage.

**patency** State of being open or unobstructed.

**patent foramen ovale** Opening between the right atrium and left atrium that normally exists in fetal life to allow for the essential mixing of blood. The opening normally closes shortly after birth.

**percutaneous** Introduced through the skin.

**percutaneous nephrolithotomy** Uroradiologic procedure performed to extract stones from within the kidney or proximal ureter.

**percutaneous transluminal angioplasty (PTA)** Surgical correction of a vessel from within the vessel using catheter technology.

**percutaneous transluminal coronary angioplasty (PTCA)** Manipulative interventional procedure involving the placement and inflation of a balloon catheter in the lumen of a stenosed coronary artery for the purpose of compressing and fracturing the diseased material, thereby allowing subsequent increased distal blood flow to the myocardium.

**percutaneous transluminal coronary rotational atherectomy (PTCRA)** Manipulative interventional procedure involving a device called a Rotablator to remove atherosclerotic plaque from within the coronary artery using a high-speed rotational burr.

**percutaneously** Performed through the skin.

**pericardium** Fibrous sac that surrounds the heart.

**planimetry** Mechanical tracing to determine the volume of a structure.

**pledget** Small piece of material used as a dressing or plug.

**portal circulation** System of vessels carrying blood from the organs of digestion to the liver.

**pulmonary circulation** System of vessels carrying blood from the heart to the lungs and back to the heart.

**pulse** Regular expansion and contraction of an artery that is produced by the ejection of blood from the heart.

**pulse oximetry** Measurement of oxygen saturation in the blood via an optic sensor placed on an extremity.

**reperfusion** Reestablishment of blood flow to the heart muscle through a previously occluded artery.

**restenosis** Narrowing or constriction of a vessel, orifice, or other type of passageway after interventional correction of primary condition.

**rotational burr atherectomy** Ablation of atheroma through a percutaneous transcatheter approach using a high-speed rotational burr.

**serial imaging** Acquisition of images in rapid succession.

**stenosis** Narrowing or constriction of a vessel, an orifice, or other type of passageway.

**stent** Wire-mesh or plastic conduit placed to maintain flow.

**systemic circulation** System of vessels carrying blood from the heart out to the body (except the lungs) and back to the heart.

**systole** Contraction phase of the atria or ventricles of the heart during which blood is ejected from the chambers; Point in the cardiac cycle at which the heart is contracting (at work).

**tachyarrhythmia** Irregular heart rhythm in conjunction with tachycardia.

**tachycardia** Any heart rhythm having an average heart rate in excess of 100 beats per minute.

**targeted lesion** Area of narrowing within an artery where a revascularization procedure is planned.

**thrombogenesis** Formation of a blood clot.

**thrombolytic** Capable of causing the breakup of a thrombus.

**thrombosis** Formation or existence of a blood clot.

**thrombus** Blood clot obstructing a blood vessel or cavity of the heart.

**transducer** Device used to convert one form of energy into another. Transducers used in cardiac catheterization convert fluid (blood) pressure into an electrical signal displayed on a physiologic monitor.

**transluminal extraction atherectomy** Excision and aspiration of atheroma and thrombus through a percutaneous transcatheter approach using a low-speed cutting and suction device.

**transposition of the great arteries** Congenital heart defect requiring interventional therapy. In this defect the aorta arises from the right side of the heart and the pulmonary artery arises from the left side of the heart.

**umbrella** Prosthetic interventional device consisting of two opposing polyurethane disks connected by a central loop mounted on a spring-loaded assembly to provide opposing tension.

**uroradiology** Radiologic and interventional study of the urinary tract.

**valvular competence** Ability of the valve to prevent backward flow while not inhibiting forward flow.

**varicies** Irregularly swollen veins.

**vasoconstriction** Temporary closure of a blood vessel using drug therapy.

**vein** Vessel that carries blood from the capillaries to the heart.

**venography** Radiologic study of veins after the injection of radiopaque contrast medium.

**venotomy** Surgical opening of a vein.

**ventricle** One of two larger pumping chambers of the heart.

**venule** Any of the small blood vessels that collect blood from the capillaries and join to become veins.



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27

# SECTIONAL ANATOMY FOR RADIOGRAPHERS

TERRI BRUCKNER

## OUTLINE

Overview, 132  
Cranial region, 132  
Thoracic region, 142  
Abdominopelvic region, 150  
SUMMARY OF ANATOMY, 166

MRI through midsagittal plane.





## Overview

An understanding of the relationships between visceral and skeletal structures is essential for the identification and localization of specific anatomic structures using computed imaging modalities. The trend in the development of new imaging methods is toward sectional reconstruction, whether using x-ray techniques, magnetic resonance imaging (MRI), or diagnostic medical sonography. The purpose of this chapter is to provide the radiographer who possesses a background in general anatomy with an orientation to sectional anatomy and to correlate that anatomy with structures demonstrated on images from the various computer generated imaging modalities.

The cadaver sections depicted in this chapter were selected as being representative of major organ structures for each of the body regions and are *depicted from the inferior surface*. The major anatomic structures normally seen when using current imaging modalities are labeled. For each cadaver section presented, representative images are included to provide an orientation to anatomic structures normally seen using the available imaging modalities. The cadaver sections and diagnostic images do not match exactly; therefore some structures are seen on only one of the illustrations for each body region.

When *axial images* are viewed, it is useful to imagine standing at the patient's feet and looking toward the head. With this orientation the patient's right side is to the viewer's left and vice versa. The anterior aspect of the patient is usually at the top of the image, and the posterior is at the bottom. All relational terms in the following discussion refer to the body in normal anatomic position.

## Cranial Region

The computed tomography (CT) localizer, or scout, image (Fig. 27-1) provides a lateral image of the cranium. CT imaging for the cranium may be performed with the gantry parallel to or angled 15 to 20 degrees to the orbitomeatal line (OML). MRI of the cranium generally results in images that are parallel to the orbitomeatal or infraorbitomeatal plane. More details on patient positioning for CT are provided in Chapter 33, and information on patient positioning for MRI is provided in Chapter 36. Because the imaging planes may be different for the cadaver sections and the CT and MRIs, some variation exists in the anatomic structures visualized on corresponding illustrations in this section.

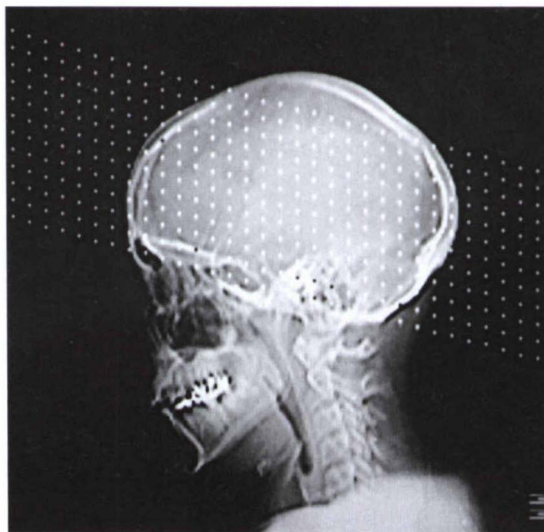


Fig. 27-1 CT localizer (scout) image of skull.

Three identifying lines represent the approximate levels for each of the labeled cadaver sections and images for this region. The cranial cadaver section seen in Fig. 27-2 is sectioned through the frontal and parietal bones. The *cortex*, or *outer layer of gray matter*, is clearly differentiated from the deeper *white matter*. The numerous *gyri*, or *convolutions*, and *sulci* are demonstrated. The *cerebral hemispheres* are separated by the *longitudinal cerebral fissure*. Invaginated in this fissure is a fold of *dura mater*, the *falx cerebri*. The *superior sagittal sinus* is a venous drainage system that runs through the superior margin of the falx and follows the contour of the superior skull margin. In cross section, the anterior and posterior aspects of this sinus can normally be seen in the midline deep to the bony plates. (Only the posterior portion of the sinus is visible in Fig. 27-2.) Two of the five *cerebral lobes* are seen (frontal and parietal). The division between these lobes is the *central sulcus*. The *corona radiata* is a central tract of white matter that connects all parts of the cerebral hemisphere to the internal capsule and other parts of the central nervous system. This section demonstrates the most superior portion of the corpus callosum and the roof of the lateral ventricle on the left side.

Fig. 27-3 is a CT image demonstrating the same structures as the cadaver section in Fig. 27-2. However, the *superior sagittal sinus* appears white because of the introduction of contrast medium.

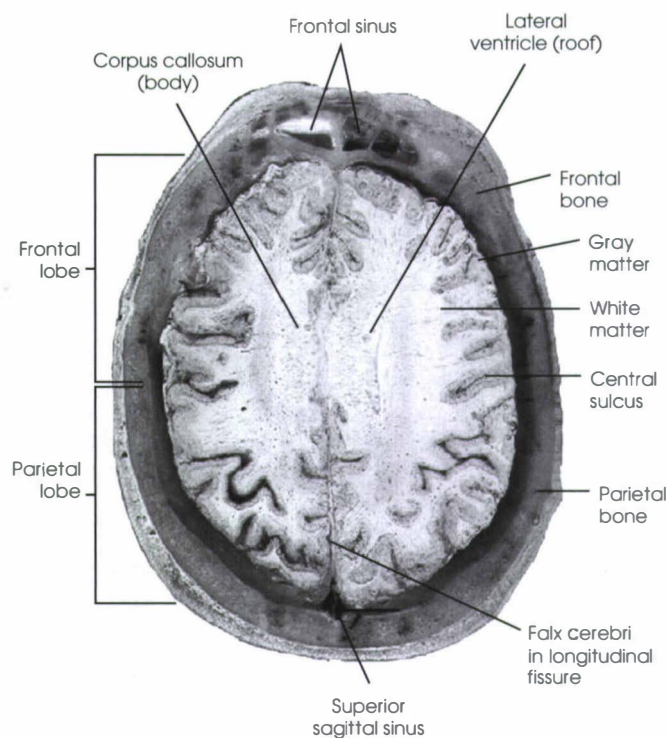


Fig. 27-2 Cadaver section corresponding to level A in Fig. 27-1.

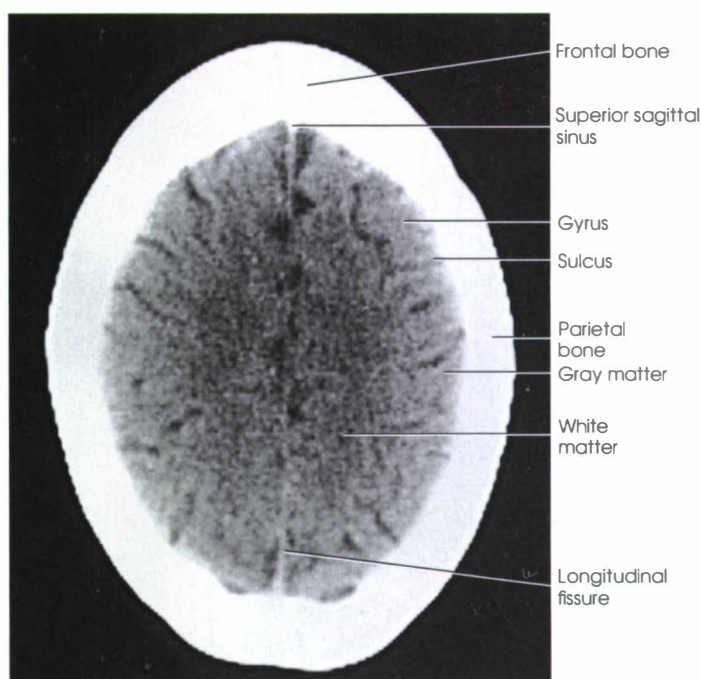


Fig. 27-3 CT image representing the anatomic structures located at level A in Fig. 27-1.



The axial section through the midcranial region demonstrates many of the central structures of the cerebral hemispheres (Fig. 27-4). The falx cerebri is shown within the longitudinal fissure, with the superior sagittal sinus in the posterior margin. The hemispheres are joined by a tract of white fibers known as the *corpus callosum*. The corpus callosum is shaped like an inverted U; therefore in cross section at this level, only the anterior and posterior portions can be seen. The anterior portion of the corpus callosum is called the *genu*, and the posterior portion is the *splenium*. This skull is sectioned so that only the splenium is seen in Fig. 27-4. In this section the *frontal*, *temporal*, and *occipital lobes* are visualized along with the *insula* (fifth lobe or island of Reil), which is deep to the temporal lobe at the lateral fissure.

At this level the *anterior* and *posterior horns* of the *lateral ventricles* are seen. The membranous layer of tissue between the anterior horns is the *septum pellucidum*. Within each posterior horn is a portion of the *choroid plexus*, a capillary network responsible for the formation of cerebrospinal fluid (CSF). Deep to the cortex, much of the cerebrum is composed of tracts of white matter. Several areas of gray matter are found deep within the white matter. These areas of gray matter relay and coordinate information and are known collectively as the *basal nuclei*, or "ganglia" or the cerebral nuclei. The major components of the basal nuclei seen at this level are (from lateral to medial) the *claustrum*, *lentiform nucleus* (composed of the putamen and globus pallidus), and the *caudate nucleus*. The lentiform nucleus is separated from the caudate nucleus and thalamus by a tract of white matter known as the *internal capsule*. The

caudate nucleus is located lateral to the anterior horn of the lateral ventricle. This section is just superior to the *midline third ventricle*. The *thalamus*, which serves as a central relay station for sensory impulses to the cerebral cortex, forms the lateral walls of the third ventricle.

On a slightly more inferior section, the *pineal body* would be visualized between the third ventricle and the splenium of the corpus callosum. This is an important radiographic landmark because of its tendency to calcify in adults. The terminal branches of the internal carotid artery are the *anterior* and *middle cerebral arteries*. The anterior cerebral artery branches toward the midsagittal plane and enters the longitudinal fissure where it curls around the external surface of the corpus callosum. The middle cerebral artery extends laterally to the lateral fissure and branches are given off that supply the temporal and parietal lobes. At this level, branches of the anterior cerebral arteries are found in the longitudinal cerebral fissure, just anterior to the genu of the corpus callosum. Branches of the middle cerebral arteries are found in the lateral fissure. This figure demonstrates several structures associated with the nose and orbit. The nasal bones and nasal septum are clearly identified. Near the posterior end of the septum, multiple air-cells are seen, which are the ethmoidal sinuses. Within the bony orbit lies the globe. The lens of each eyeball is seen in the anterior region of each globe. Projecting posteriorly from the right globe is a portion of the optic nerve.

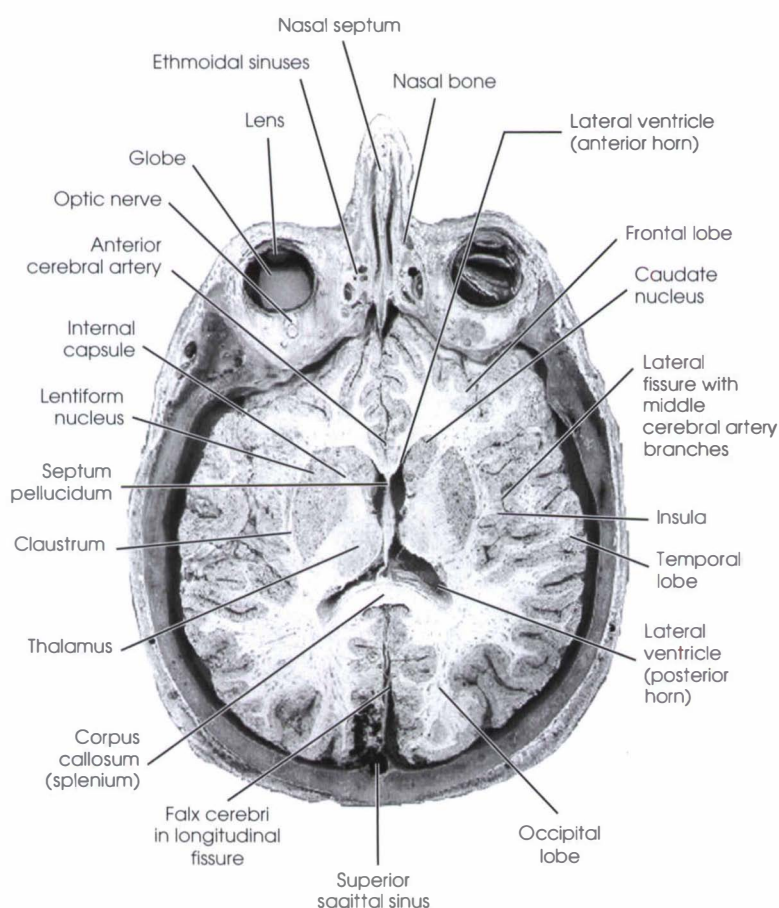


Fig. 27-4 Cadaver section corresponding to level B in Fig. 27-1.

The MRI in Fig. 27-5 corresponds to the cadaver section discussed previously. In this T1-weighted image, bone cortex appears black because of a lack of signal return. The high content of fat in the marrow cavity appears white on these images. CSF within the ventricles appears dark. Note the differentiation between gray and white matter structures.

The cross section through the lower cranium demonstrates the inferior portions of the cerebrum, brainstem, cerebellum, and associated major skeletal structures (Fig. 27-6). The maxilla, maxillary sinuses, and the inferior nasal conchae are seen in the anterior skull. The temporal lobes are found in the middle cranial fossa between the *lesser wings* of the sphenoid bone and the *pars petrosa* of the temporal bone. This section is just inferior to the *pituitary gland* which is located in the *hypophyseal fossa* of the *sella turcica*, in the body of the sphenoid bone. The *internal carotid arteries* lie lateral to the sella turcica. Posterior to the sphenoid bone is the *pons*, a portion of the brain that relays impulses between the *medulla oblongata* and *cerebrum*. Extending laterally and anteriorly from the pons are the *trigeminal nerves*. The *basilar artery* lies in the midline directly anterior to the pons. The major portion of the posterior fossa is occupied by the cerebellum.

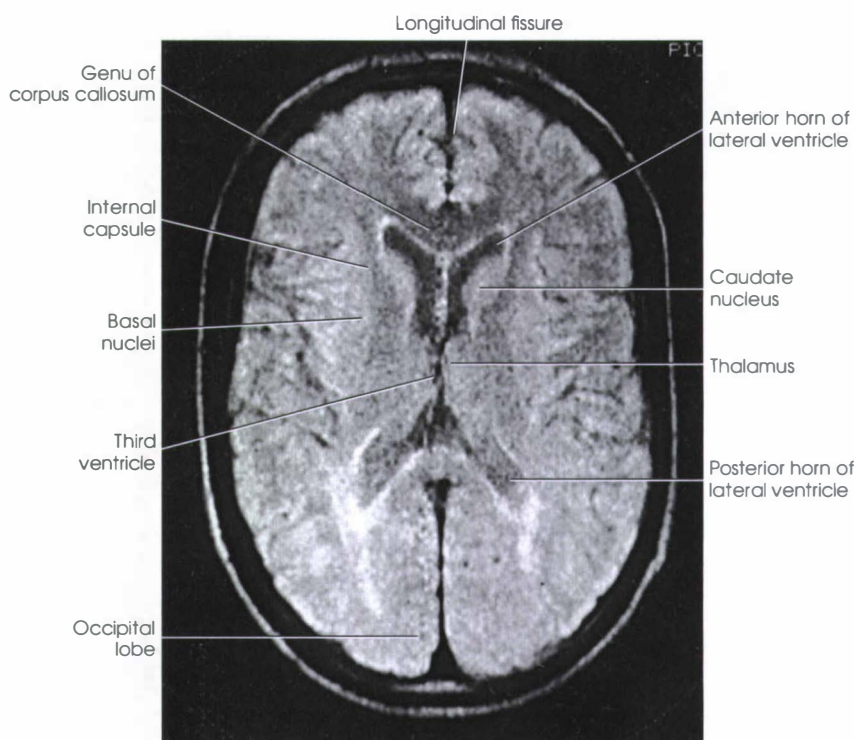


Fig. 27-5 MRI representing the structures located at level B in Fig. 27-1.

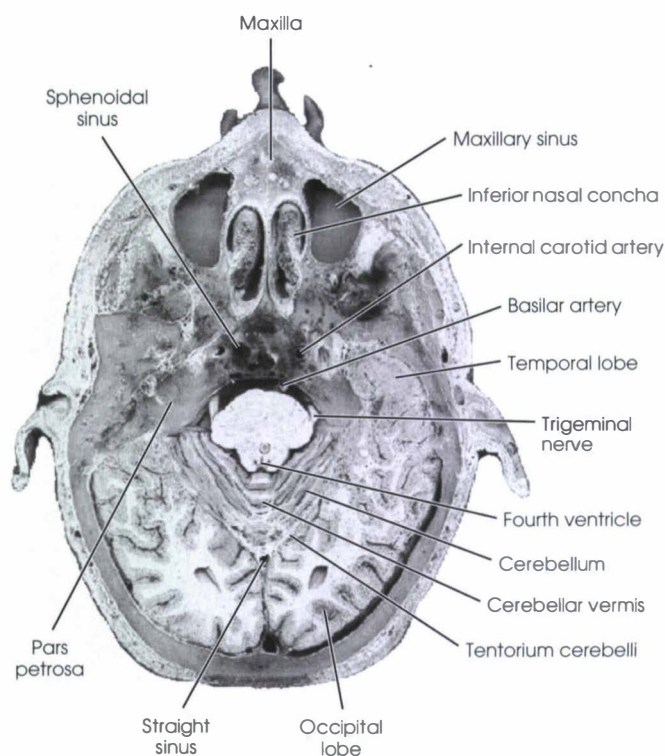


Fig. 27-6 Cadaver section corresponding to level C in Fig. 27-1.



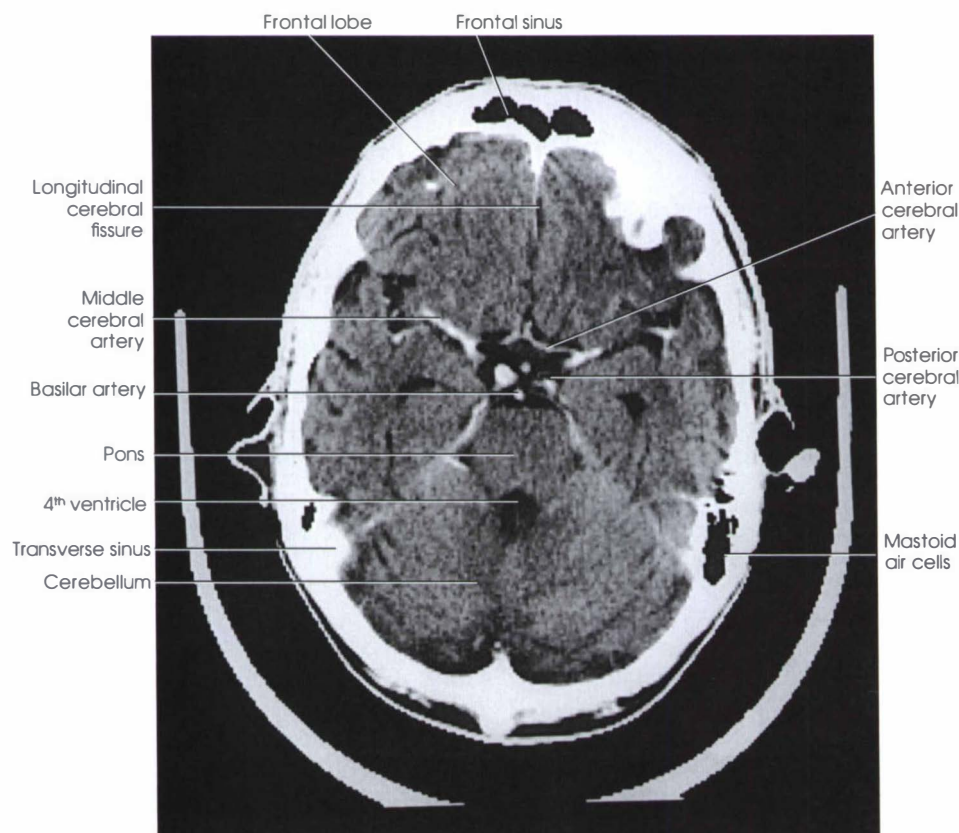


Fig. 27-7 CT image representing the anatomic structures located at level C in Fig. 27-1.

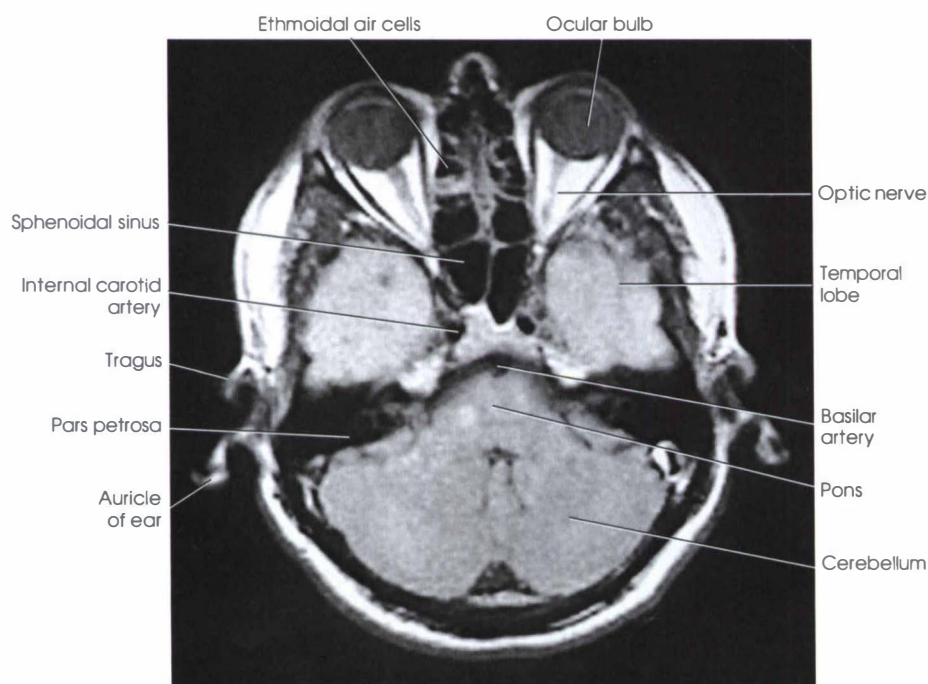


Fig. 27-8 MRI representing the anatomic structures located at level C in Fig. 27-1.

The *cerebellum* functions as a reflex center for coordinating skeletal muscle movements. It is divided into two hemispheres that are joined by the midline *vermis*. A fold of dura mater, the *tentorium cerebelli*, is found between the cerebellum and the cerebrum. Where the tentorium meets the *falx cerebri*, a venous drainage channel is formed, the straight sinus. The *fourth ventricle* is seen here beginning at the posterior pons. Fig. 27-7 is a CT scan through the region of the circle of Willis, pons, and cerebellum. Contrast medium makes the vascular structures visible on this image. The circle of Willis encircles the optic chiasm and the stalk of the pituitary gland. It is the anastomosis of the anterior and posterior blood supply to the brain. The main vessels that make up the circle of Willis are the anterior cerebral arteries, anterior communicating artery, posterior cerebral arteries, and posterior communicating arteries. The anterior and middle cerebral arteries are branches of the internal carotid artery; the posterior cerebral arteries are branches of the basilar artery, which is seen in the CT image directly anterior to the pons. Posterior to the cerebellum the transverse dural venous sinuses pass laterally in the margin of the *tentorium cerebelli*. As the transverse sinuses reach the pars petrosae, they change direction and become known as the *sigmoid sinuses*. The sigmoid sinuses ultimately exit the cranium via the *jugular foramina*, at which point they are known as the *internal jugular veins*.

Fig. 27-8 is an MRI through the orbits and posterior fossa. (Note the difference in orientation to the orbitomeatal plane between this MRI and the preceding cadaver and CT images.) The *optic nerves* can be seen extending posteriorly from the eyeballs toward the optic chiasm. The *ethmoidal air cells* and *sphenoidal sinuses* are both visualized at this level. Posterior and lateral to the sphenoidal sinuses are the *internal carotid arteries* in the carotid canal. Posterior to the sphenoidal sinuses is the *clivus*, the junction of the dorsum sellae and the basilar portion of the occipital bone. Associated with the posterior clivus are the basilar artery and pons. The black areas of signal void lateral to the pons are the dense bony pars petrosae. The *tragi* and *auricles* of the ears are seen lateral to the petrous regions.

Fig. 27-9 is a cadaver section through C3. Visualized at this level is the *hyoid bone*, which serves as an attachment for the muscles of the tongue. The *submandibular (salivary) glands* are found lateral to the hyoid at this level. Immediately posterior to the submandibular glands are the common carotid arteries. The common carotid artery bifurcates at about the level of the third cervical vertebra into the *internal* and *external carotid arteries*. The common carotid artery is enclosed in the carotid sheath along with the *internal jugular vein* and *vagus nerve*. The *vertebral arteries* can be seen in the neck within the *transverse foramina* of the cervical vertebrae. The *sternocleidomastoid muscles*, which attach to the mastoid processes and the sternum and clavicles, are visualized lateral to the internal jugular veins. Anterior to the vertebrae is the laryngeal portion of the *pharynx*. A portion of the epiglottic cartilage is seen in the anterior pharynx.

Fig. 27-10 is a CT image through the hyoid bone. This image is slightly inferior to the cadaver section and demonstrates the *symphysis* of the mandible anterior to the hyoid (with the suprahyoid muscles between). Deep to the hyoid bone is the *epiglottic cartilage*. The internal jugular vein and *common carotid arteries* (just below their bifurcation) are clearly visible because of contrast media enhancement for this particular scan.

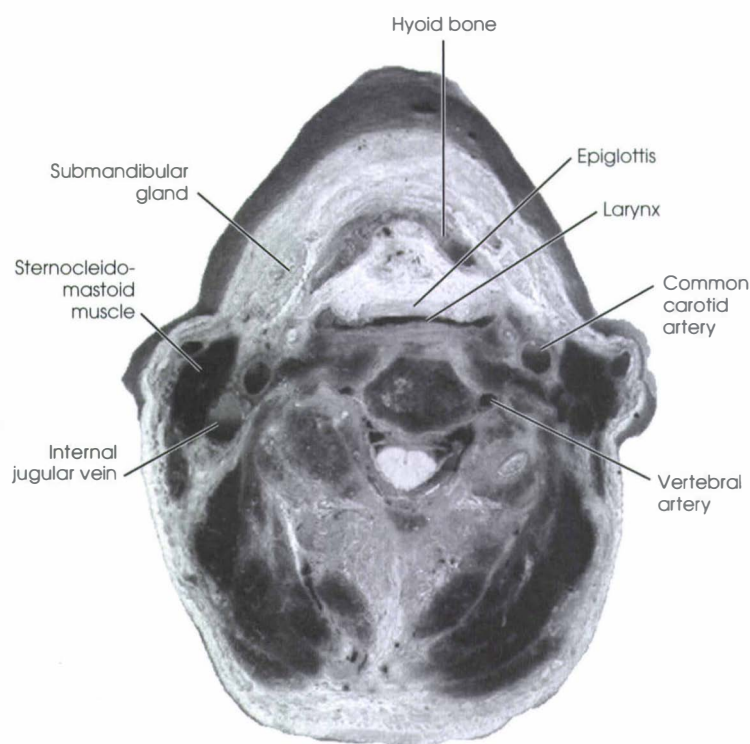


Fig. 27-9 Axial cadaver section through the C3.

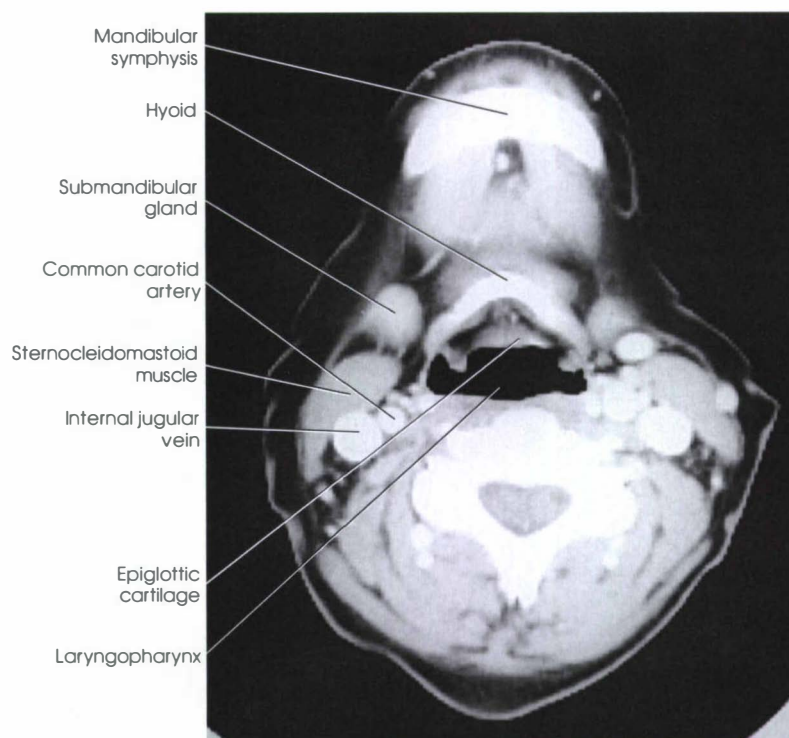


Fig. 27-10 CT image through the C4 corresponding to Fig. 27-9.



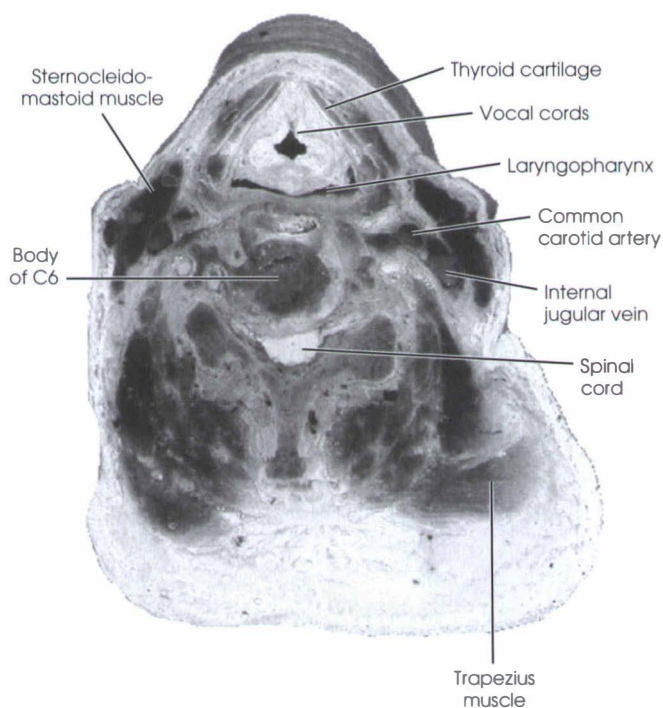


Fig. 27-11 Cadaver section through the C6.

The next cadaver section (Fig. 27-11) and CT image (Fig. 27-12) correspond to level of C6. The *thyroid cartilage* (Adam's apple) is the largest cartilage structure of the larynx and is seen surrounding the vocal cords. The *cricoid cartilage* is seen posterior to the vocal cords, and the *terminal laryngopharynx* is posterior to the *cricoid cartilage*. The trachea and esophagus begin at the inferior edge of the cricoid cartilage. The *thyroid gland* has an H-shaped configuration with two lateral lobes connected by a horizontal portion (*isthmus*). The lobes of the thyroid gland are found on the posterolateral aspects of the thyroid cartilage (and in lower sections lateral to the trachea) and appear highlighted on CT scans because of normal iodine content. At this level the common carotid artery, internal jugular vein, and vagus nerve are on each side of the pharynx and enclosed within the carotid sheath. The vagus nerve is too small to be seen on these images. The vertebral arteries are noted again within the transverse foramina of C6. The sternocleidomastoid muscles lie anterior to the internal jugular veins and lateral to the thyroid cartilage at this level. The large posterior muscle masses lateral to the vertebral column are the *trapezius muscles*.

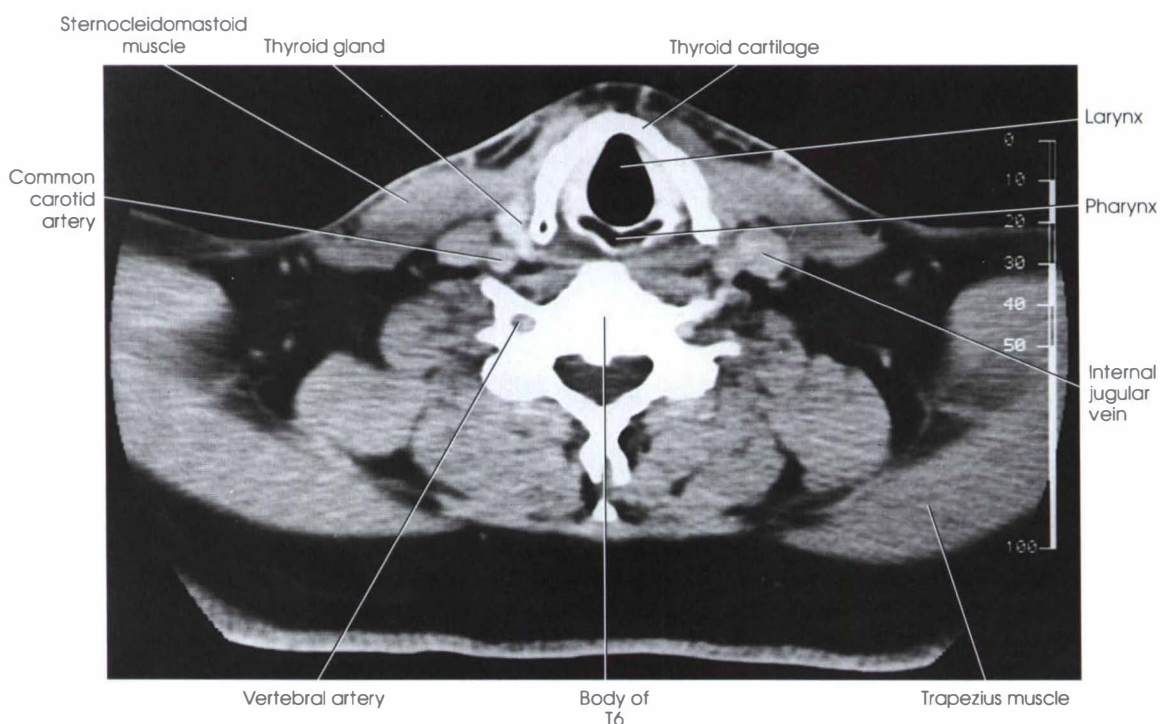


Fig. 27-12 CT image through the C6 corresponding to Fig. 27-11.

It is increasingly common to find images in sagittal, coronal, and oblique planes. CT scanners have the capability to generate images in the axial and coronal planes and to reconstruct the information in alternate planes. MRI, on the other hand, is capable of direct axial, sagittal, oblique, and coronal imaging. Representative images have been selected in the sagittal and coronal planes to help interpret the anatomy demonstrated.

Fig. 27-13 is a midsagittal MRI of the cranium. The relationship between the cerebral hemisphere, cerebellum, and brainstem is demonstrated. In this image the frontal, parietal, and occipital lobes of the cerebrum are seen and correspond to the cranial bones. The corpus callosum is a white matter tract that connects the hemispheres and is found at the inferior aspect of the frontal and parietal lobes. CSF appears dark on this T1-weighted image, making it relatively easy to trace the ventricular system. The anterior horn of the lateral ventricle is inferior to the genu of the corpus callosum. The third ventricle lies in the midline, between the two lateral ventricles. The lateral ventricles produce a great deal of CSF, which is transported to the third ventricle by way of the *intraventricular foramen (of Monro)*. The third ventricle is not optimally visualized in this image. What is actually seen is the thalamus, which forms the lateral wall of the third ventricle. CSF drains from the third ventricle via the *cerebral aqueduct (of Sylvius)*, which can be found within the midbrain (between the *corpora quadrigemina* and the *cerebral peduncles*). The *fourth ventricle* is also a midline structure and is situated between the pons and cerebellum. The large air-filled sphenoidal sinus is located anterior to the pons. Superior to this, the pituitary gland rests within hypophyseal fossa formed by the sella turcica. Directly superior to the pituitary gland is the optic chiasm.

Several vascular structures are well demonstrated in Fig. 27-13. The basilar artery appears between the clivus and pons. The *great cerebral vein (of Galen)* is posterior to the splenium of the corpus callosum. Between the cerebrum and cerebellum, the *straight sinus* (one of the dural venous sinuses) is noted within the tentorium cerebelli. This vessel is formed by the junction of the inferior sagittal sinus and the great cerebral vein (of Galen).

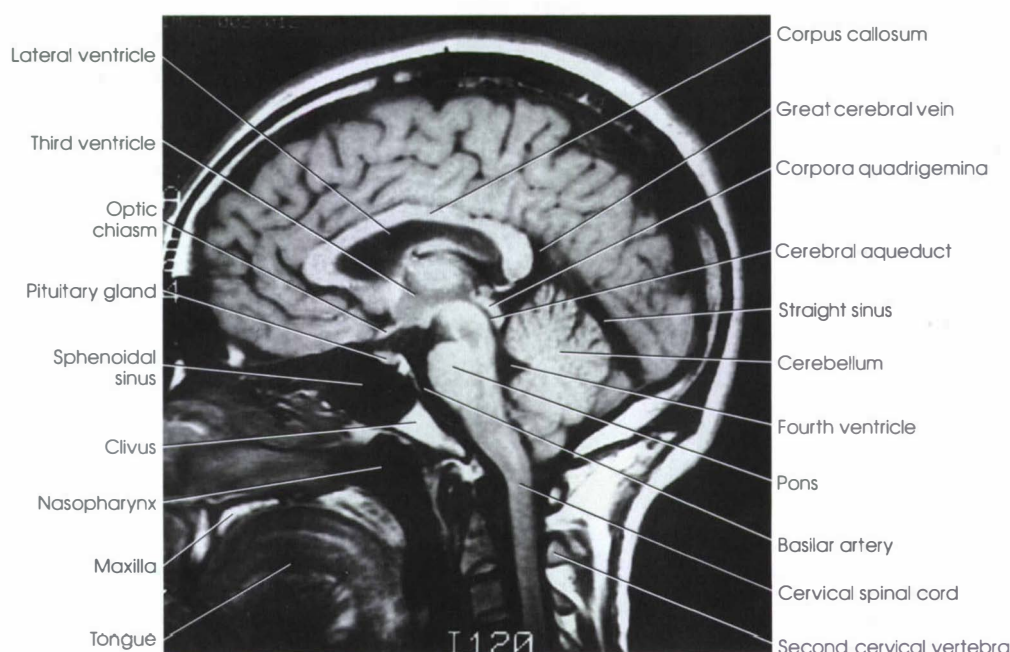


Fig. 27-13 MRI through midsagittal plane.



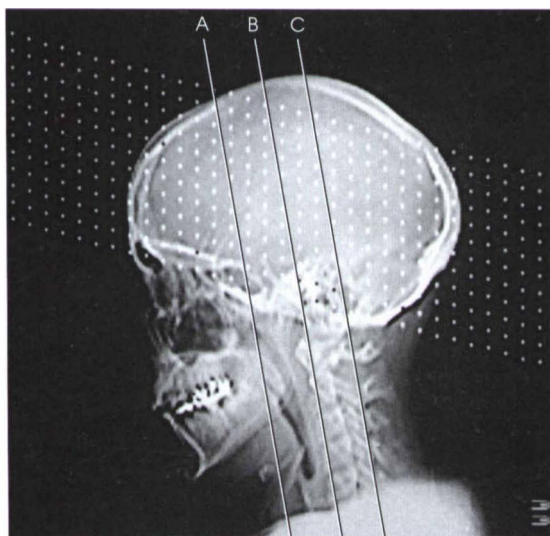


Fig. 27-14 CT localizer (scout) image of the skull.

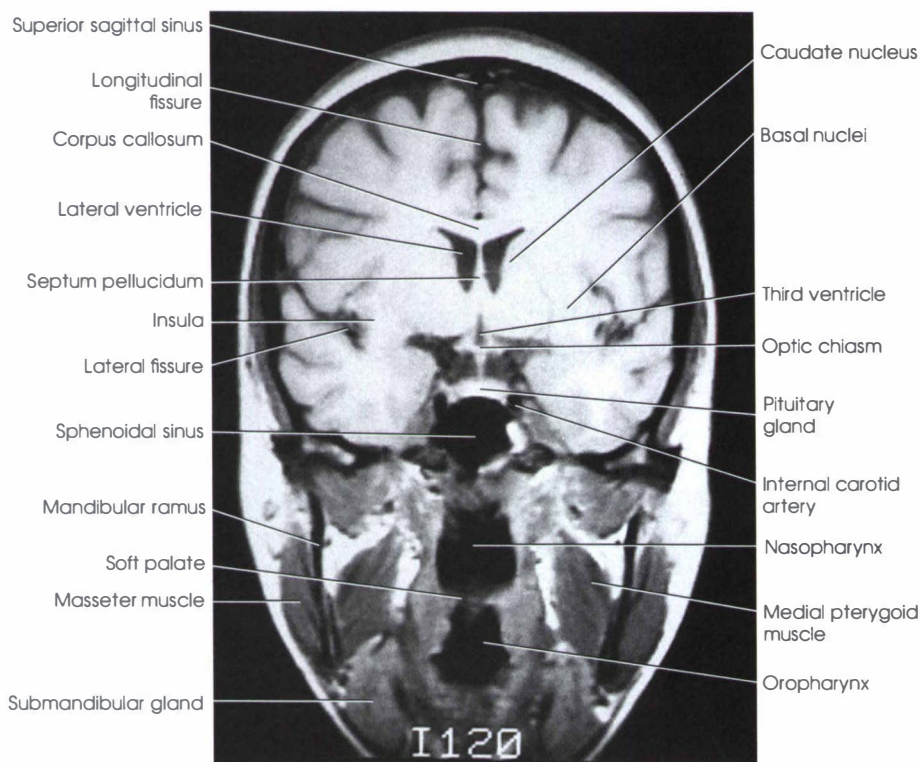


Fig. 27-15 Coronal MRI corresponding to level A in Fig. 27-14.

A CT localizer, or scout, image (Fig. 27-14) is included as a reference for the next three coronal images. Fig. 27-15 is a coronal MRI through the anterior horns of the lateral ventricles and the pharyngeal structures. The anterior portions of the cerebral hemispheres are joined by the corpus callosum, which is immediately superior to the lateral ventricles. The membrane between the anterior horns of the lateral ventricles is the *septum pellucidum*. On the lateral aspect of each cerebral hemisphere is the *lateral fissure*, which divides the frontal lobe from the temporal lobe. The insula lies deep to this fissure.

Structures of the basal nuclei can again be identified. The caudate nucleus is lateral to the anterior horns. Inferolateral to the caudate nucleus are the *putamen* and *globus pallidus* (labeled basal nuclei because they are difficult to differentiate on the image). The anterior portion of the third ventricle is found in the midline inferior to the lateral ventricles. Inferior to the third ventricle are the optic chiasm and hypophysis cerebri. The *superior* and *inferior sagittal sinuses* occupy the margins of the falx cerebri in the longitudinal fissure between the hemispheres of the cerebrum. The internal carotid arteries occupy the *cavernous sinus* along with several cranial nerves and are found lateral to the hypophysis cerebri and sella turcica. Branches of the middle cerebral arteries occupy the lateral fissures of the cerebrum. Several air-filled structures are seen on this image; they are (from superior to inferior) the sphenoidal sinus, *nasopharynx*, and *oropharynx*. The soft palate can be seen between the nasopharynx and oropharynx. This image also demonstrates the *rami of the mandible* along with the *masseter* and *pterygoid muscles*. The submandibular glands, one set of salivary glands, are found deep to the *gonions* (angles) of the mandible.

Fig. 27-16 is a coronal MRI through the bodies of the lateral ventricles, the brainstem, and the bodies of the cervical vertebrae. The third ventricle is well demonstrated and bordered laterally by the thalamus. The cartilaginous structures of the *external ear* surround the *external acoustic meatus* and *canal*. The dark region (low signal return) medial to the external acoustic canal corresponds to the *petrous portion of the temporal bone*. Within this region the *seventh and eighth (facial and vestibulocochlear) cranial nerves* are found in the *internal acoustic canal*. The first three cervical vertebrae are detailed in this section with the *dens* of the *axis* (C2) seen between the lateral masses of the *atlas* (C1). The vertebral arteries are demonstrated within the transverse foramina, lateral to the bodies of cervical vertebrae. The internal carotid arteries and the internal jugular veins are found more laterally in the neck between the sternocleidomastoid muscles and cervical spine. The large whitish masses inferior to the external acoustic canals are the *parotid glands*.

Fig. 27-17 shows a coronal MRI through the lateral ventricles, brainstem, and spinal cord. The splenium of the corpus callosum is found between the lateral ventricles. Inferior to the splenium is the midline pineal body. The cerebral aqueduct is also a midline structure found within the midbrain. On either side of the cerebral aqueduct are the *superior and inferior colliculi*, which are associated with visual and auditory reflexes. Two large white matter tracts are seen extending laterally, inferior to the colliculi. These are the middle cerebellar peduncles, which conduct impulses between the pons and cerebellum. Portions of the cerebellum are visualized superior and inferior to the middle cerebellar peduncles. The medulla oblongata is the most inferior segment of the brainstem and is continuous with the spinal cord as it passes through the foramen magnum. The large dark areas (signal void) lateral to the cerebellum correspond to the bony mastoid portions of the temporal bone.

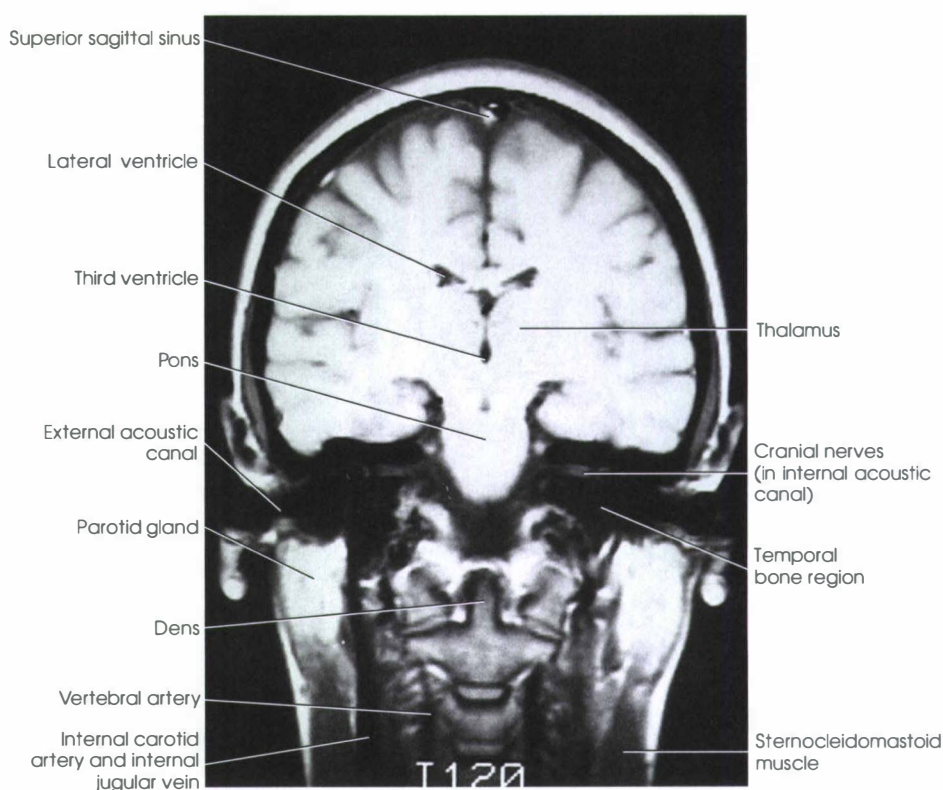


Fig. 27-16 Coronal MRI corresponding to level B in Fig. 27-14.

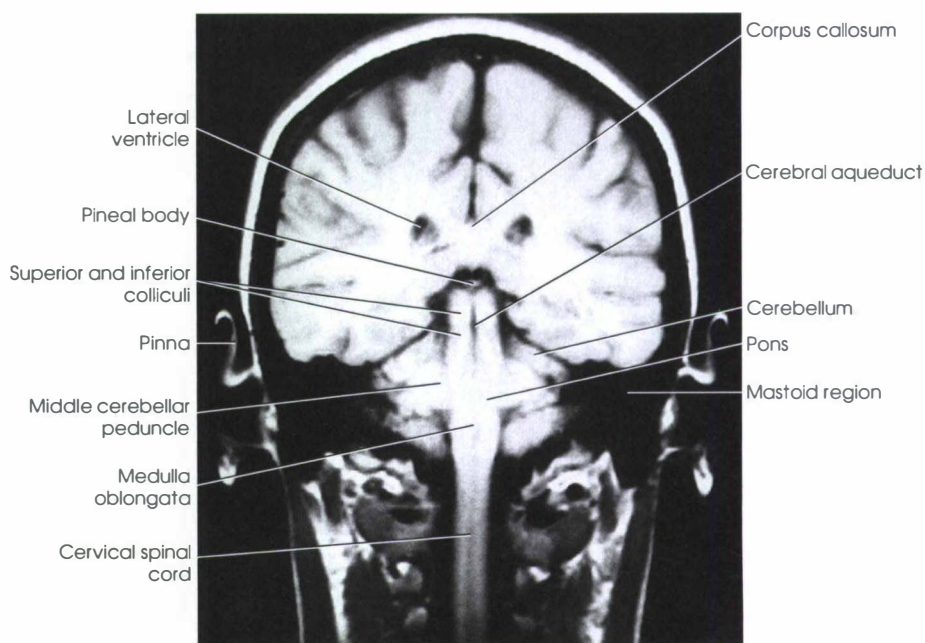


Fig. 27-17 Coronal MRI corresponding to level C in Fig. 27-14.



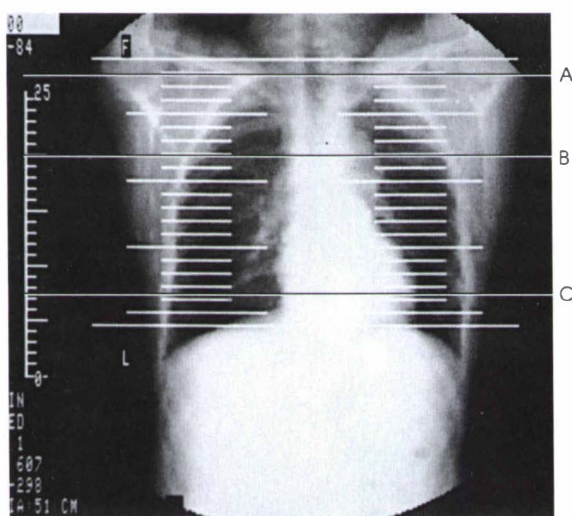


Fig. 27-18 CT localizer (scout) image of thorax.

## Thoracic Region

The CT localizer, or scout, image represents an AP projection of the thoracic region with three identifying lines (Fig. 27-18). These lines demonstrate the approximate three levels for each of the labeled cadaver sections for this region.

Figs. 27-19 and 27-20 represent respectively a cadaver section and CT image at the level of T2 and demonstrate the relationship between the vertebral column, esophagus, and trachea. The inferior portion of the *thyroid gland*, which extends from C6 to T1, is positioned anterior to the *trachea* in the cadaver image. The *vertebral arteries* are positioned lateral to the vertebral column, and the *common carotid arteries* are found lateral to the trachea. At this level the *internal jugular veins* have joined the subclavian veins to form the brachiocephalic veins, best seen between the subclavian artery and the carotid artery on the patient's right side. The *apices* of the lungs are visualized along with the first two *ribs*, the *glenohumeral joint*, and the *sternal extremity of the clavicle*. The *trapezius*, *pectoral*, and *deltoid muscles* are clearly seen. The muscles of the *rotator cuff* (supraspinatus, infraspinatus, subscapularis, and teres minor) stabilize the glenohumeral joint. At this level the *supraspinatus*, which lies superior to the scapular spine, is visible on the cadaver section.

The CT scan at this level is slightly more inferior than the cadaver image. The five major vessels of the superior thorax are visualized posterior to the manubrium. The right and left *brachiocephalic veins* are formed by the junction of the *subclavian veins* and the internal jugular veins. The brachiocephalic veins will unite and form the *superior vena cava* at a more inferior level. The three branches of the *aortic arch* are also visualized on this image. From the patient's right to left they are the *brachiocephalic artery*, *left common carotid artery*, and *left subclavian artery*. The brachiocephalic artery gives rise to the right subclavian and right common carotid arteries, which are both seen in more superior sections of the thorax.

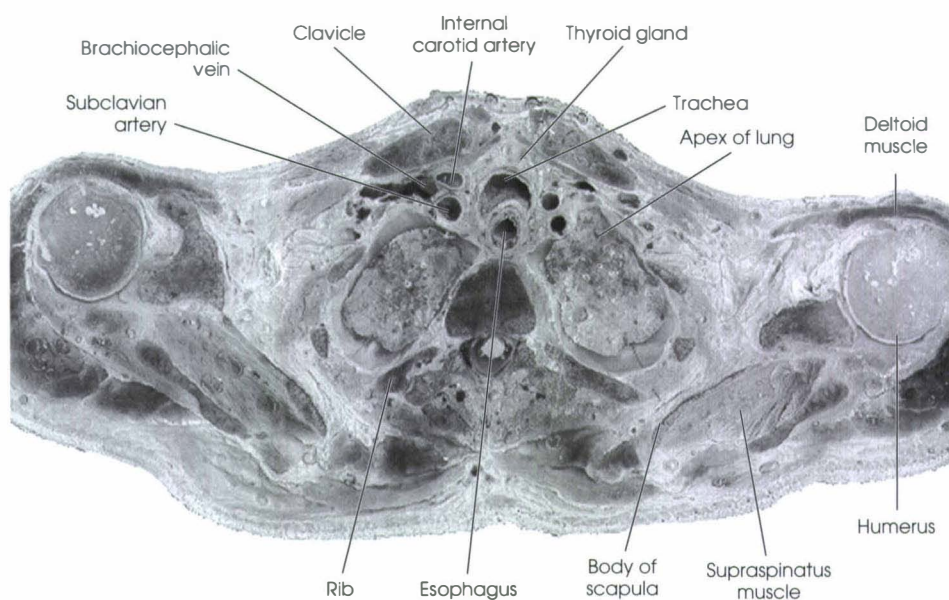


Fig. 27-19 Cadaver section corresponding to level A in Fig. 27-18 at T2.

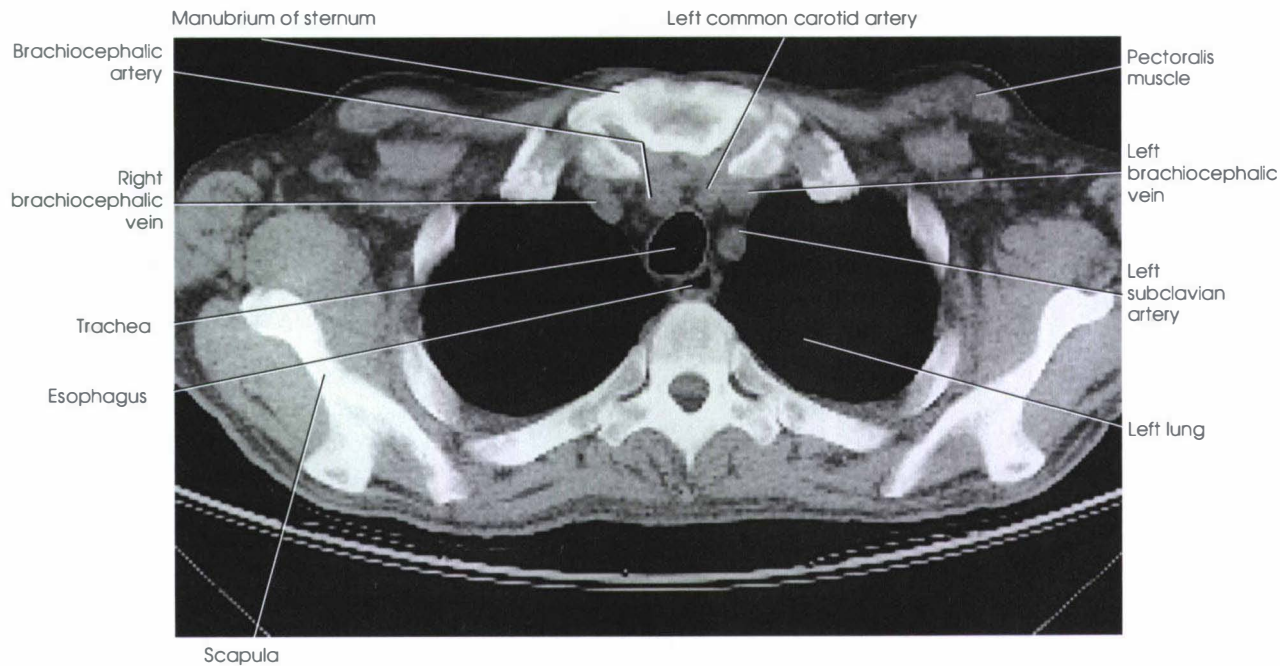


Fig. 27-20 CT image corresponding to Fig. 27-19.



Figs. 27-21 and 27-22 represent respectively a cadaver section and CT image at the level of T5 and demonstrate the great vessels superior to the heart. (The heart is normally positioned between T7 and T11, with the majority of the organ lying left of the midline.) The *ascending aorta* is found anteriorly in the midline; the *descending aorta* is related to the left anterolateral surface of the vertebral bodies. (This relationship between the descending aorta and vertebral column is continuous through the thorax and abdomen.) Note the normal difference in caliber between the ascending and descending aorta. The superior vena cava is located to the right of the ascending aorta, and the pulmonary trunk and left pulmonary artery are located to the left of the ascending aorta at this level. The *pulmonary trunk* originates from the right ventricle of the heart and divides into the right and left *pulmonary arteries*, which carry deoxygenated blood to the lungs. In Figs. 27-21 and 27-22 the branches of the right and left pulmonary arteries are seen at the *hilum* of each lung. The *azygos vein*, which drains the thoracic and posterior abdominal walls, is positioned anterior and to the right of the vertebral column from its origination near the diaphragm until it arches anteriorly over the root of the right lung and empties into the superior vena cava at the level of T4 or T5. At the T5 level the trachea divides into the left and right *primary bronchi*. The *thoracic duct*, one of the major channels for lymphatic drainage, generally originates at T12 and ascends the thorax in the posterior mediastinum between the aorta and azygos vein. The duct ultimately empties into the venous blood system at the junction of the left subclavian and internal jugular veins.

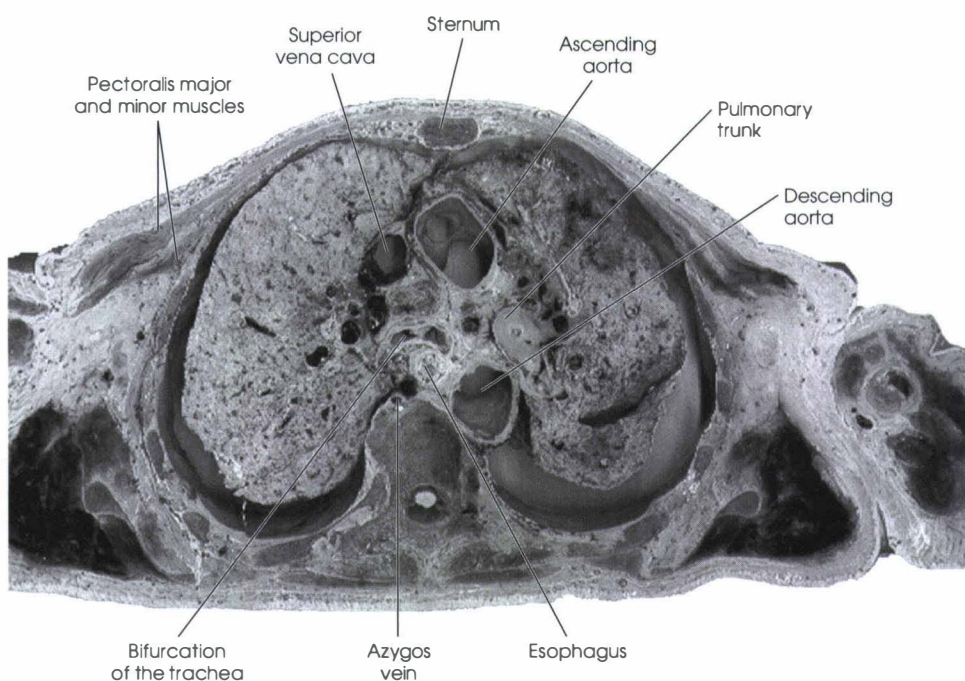


Fig. 27-21 Cadaver section corresponding to level B of Fig. 27-18 at T5.

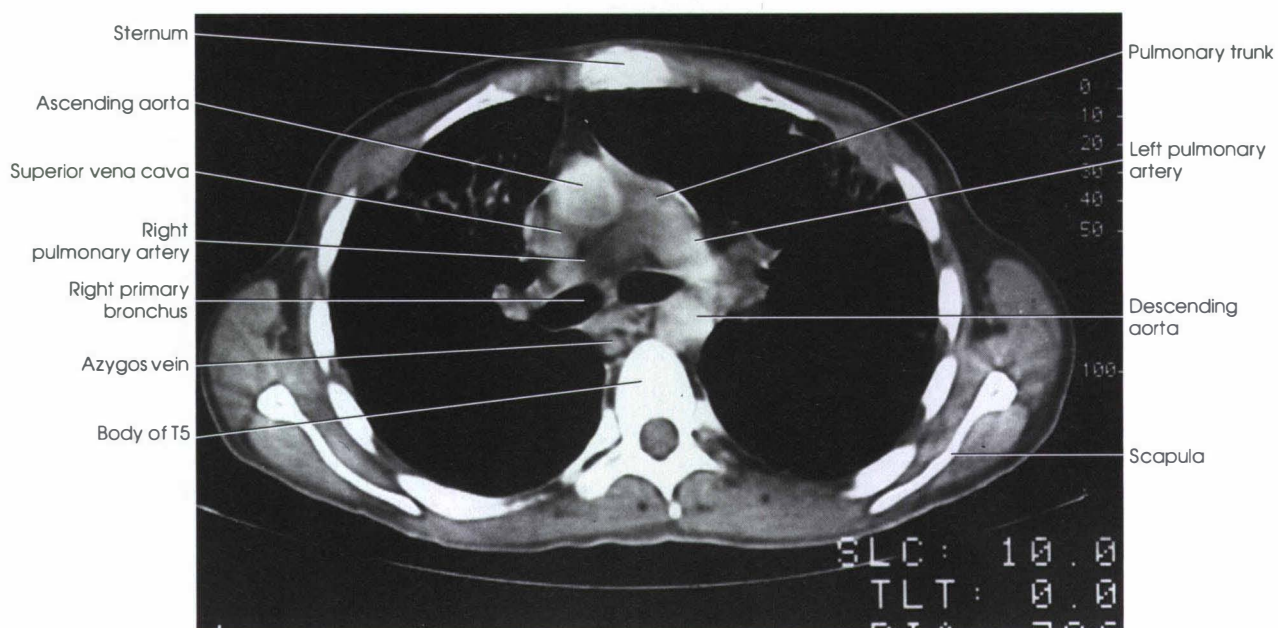


Fig. 27-22 CT image corresponding to Fig. 27-21.



The cadaver section and CT image depicted respectively in Figs. 27-23 and 27-24 demonstrate the *lungs* and the midsection of the *heart*. Generally when the heart is imaged in cross section, the *left atrium* is the most superior structure encountered, and the *pulmonary veins* are seen emptying into it (not seen in these figures). The *right atrium* is seen lying the farthest toward the right side of the body, anterior and somewhat inferior to the left atrium. The *inferior vena cava (IVC)* may be seen at this level as it enters the right atrium. The *right ventricle* lies to the left of the right atrium and anterior to the more muscular *left ventricle*. The *inter-ventricular septum* can be seen between the ventricles.

The lungs are divided into superior and inferior lobes by the diagonally oriented *oblique fissure*. The *superior lobes* lie superior and anterior to the inferior lobes. The *superior lobe* of the right lung is further divided by the *horizontal fissure*, with the lower portion termed the *middle lobe*. The left lung has no horizontal fissure. The inferior and anterior portion of the left lung (corresponding to the right middle lobe) is termed the *lingula*.

Muscular structures that can be seen at this level include the inferior insertions of the trapezius, the *latissimus dorsi*, and the *serratus anterior muscles*. The *esophagus* is normally seen anterior and slightly to the left of the vertebral column at this level as it veers toward the *esophageal hiatus* of the diaphragm. Fig. 27-24 demonstrates the superior portion of the liver bulging against the base of the right lung. The descending aorta normally lies along the left anterolateral surface of the vertebral column, and the azygos vein is normally on the right anterolateral surface. Because of patient pathology the azygos vein, esophagus, and aorta are abnormally displaced to the left in Figs. 27-23 and 27-24.

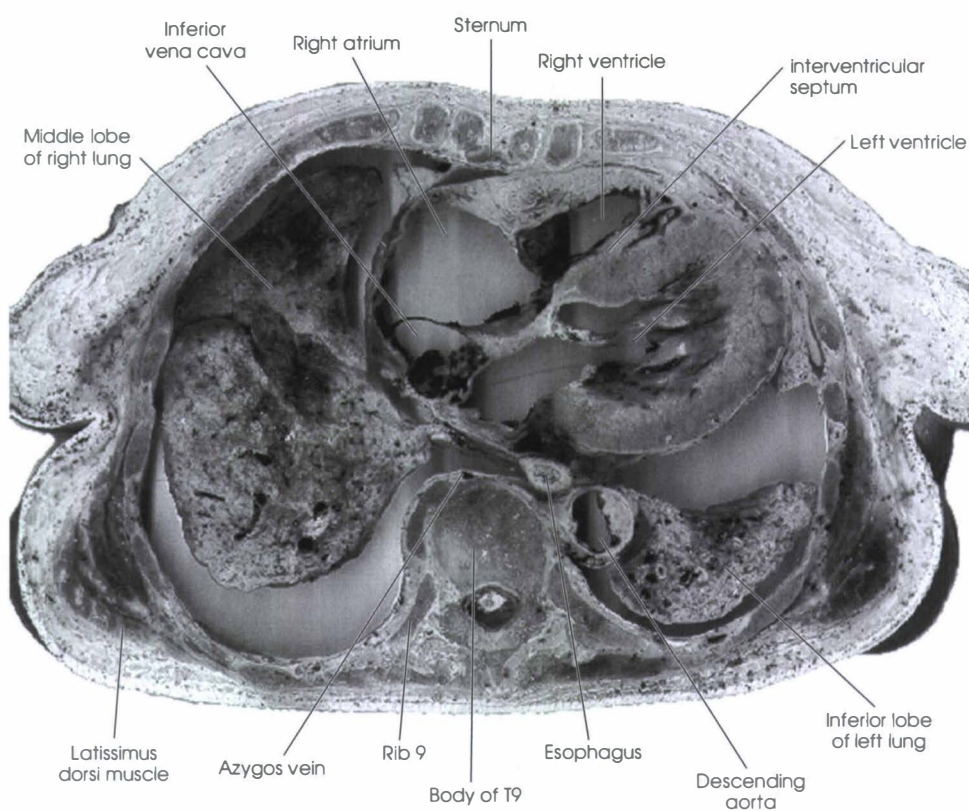


Fig. 27-23 Cadaver section corresponding to level C in Fig. 27-18 at T9.

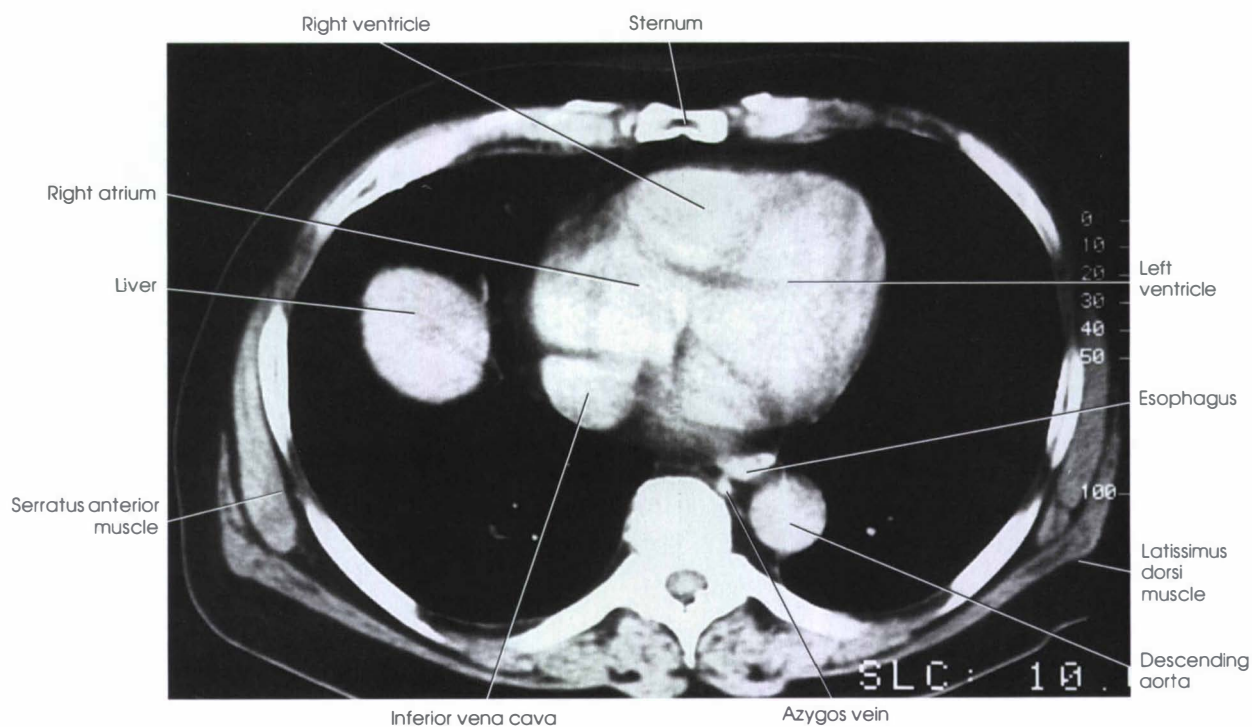


Fig. 27-24 CT image corresponding to Fig. 27-23.



Fig. 27-25 presents a sagittal MRI through the midline structures of the neck and upper thorax. The air-filled pharynx and trachea are easily identified. The cartilaginous flap within the laryngeal portion of the pharynx is the *epiglottis*. Spinal structures are clearly visible in this image and the relationship between the *intervertebral disks* and *spinal cord* is demonstrated. The major blood vessels of the superior thorax are seen posterior to the *manubrium*. The most anterior of these vessels is the left brachiocephalic vein, which ultimately unites with the right brachiocephalic vein to form the superior vena cava. Posterior to the brachiocephalic vein is a portion of the aortic arch with the origin of the brachiocephalic artery. Inferior to the arch is the right pulmonary artery.

The coronal MRI in Fig. 27-26 is slightly posterior to the midcoronal plane and also demonstrates structures of the neck and superior thorax. The distal cervical and superior thoracic vertebrae are identifiable. On the patient's left side, the *humeral head*, *clavicle*, *acromion process*, and *acromioclavicular joint* are seen. The *tracheal bifurcation* is visualized on this image. The aortic arch and left pulmonary artery are found in close proximity to the left main bronchus. From the superior aspect of the arch extends the left subclavian artery. The heart and lungs are not ideally imaged in this scan because of motion artifacts.

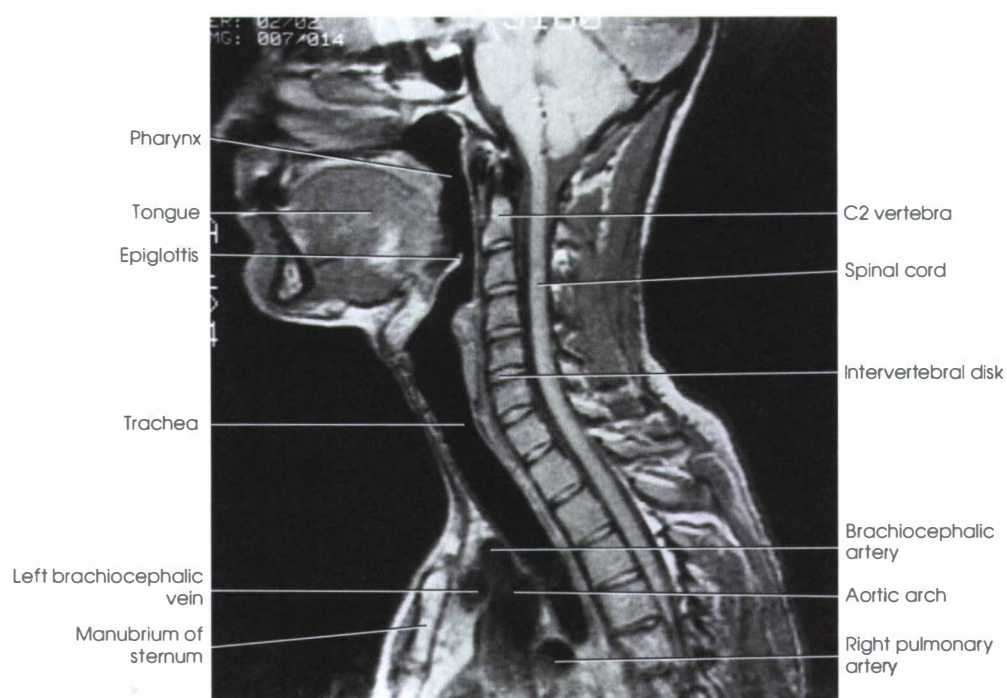


Fig. 27-25 Midline sagittal MRI through neck and upper thorax.

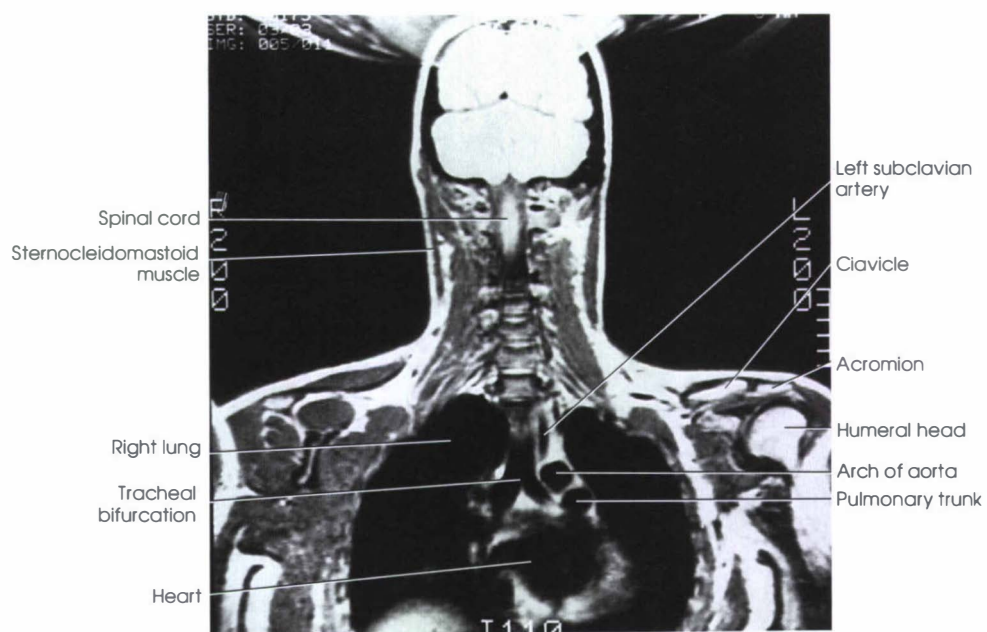


Fig. 27-26 MRI of neck and thorax through midcoronal plane.



## Abdominopelvic Region

Fig. 27-27 is a CT localizer, or scout, image representing an AP projection of the abdominopelvic region. It has six identifying lines demonstrating the levels for each of the labeled cadaver sections and images for this region.

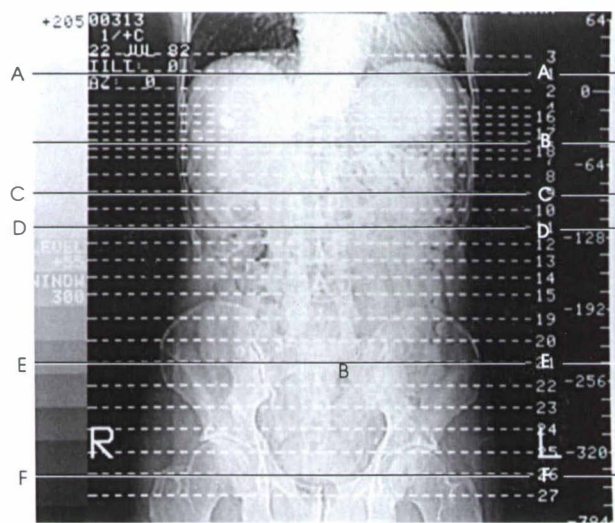


Fig. 27-27 CT localizer (scout) image of abdominopelvic region.

Figs. 27-28 and 27-29 represent structures seen at the T10-11 levels (corresponding to level A in the localizer image, Fig. 27-27). The cadaver section (Fig. 27-28) demonstrates the *right hemidiaphragm* surrounding the superior portion of the *liver* and the *left hemidiaphragm* encircling the anterior portion of the left ventricle of the heart. The pericardial fat surrounds the apex of the heart to the left of the liver. The *esophagus*, posterior to the liver, has migrated toward the patient's left as it nears its entrance into the stomach. The *aorta* is in its normal position, anterior and slightly left of the vertebral body. The IVC appears embedded within the liver. The three *hepatic veins* are draining into the IVC at this level. The CT scan (see Fig. 27-29) is at a slightly more inferior level than the cadaver section. The lower lobes of both lungs are seen. The right hemidiaphragm surrounds the superior portion of the liver. The *spleen* and contrast-filled *stomach* are seen on the patient's left side, where they are surrounded by the left hemidiaphragm and lower lobe of the left lung. The esophagus still appears in the midline. The IVC is difficult to see in this image because of its proximity to the isodense liver tissue.

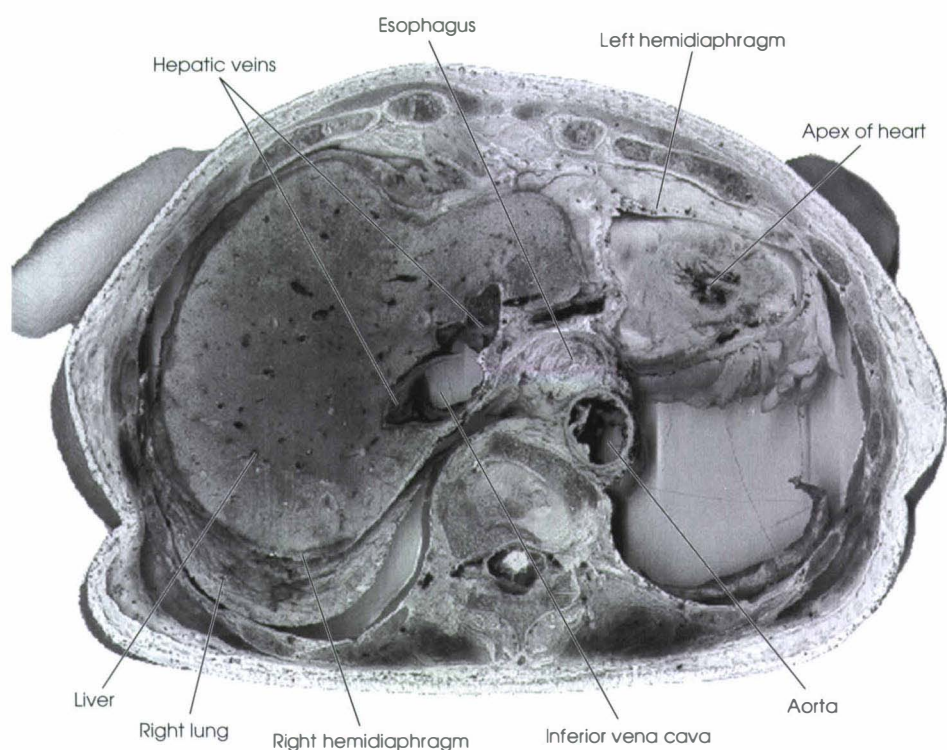


Fig. 27-28 Cadaver section corresponding to level A in Fig. 27-27 at T10.

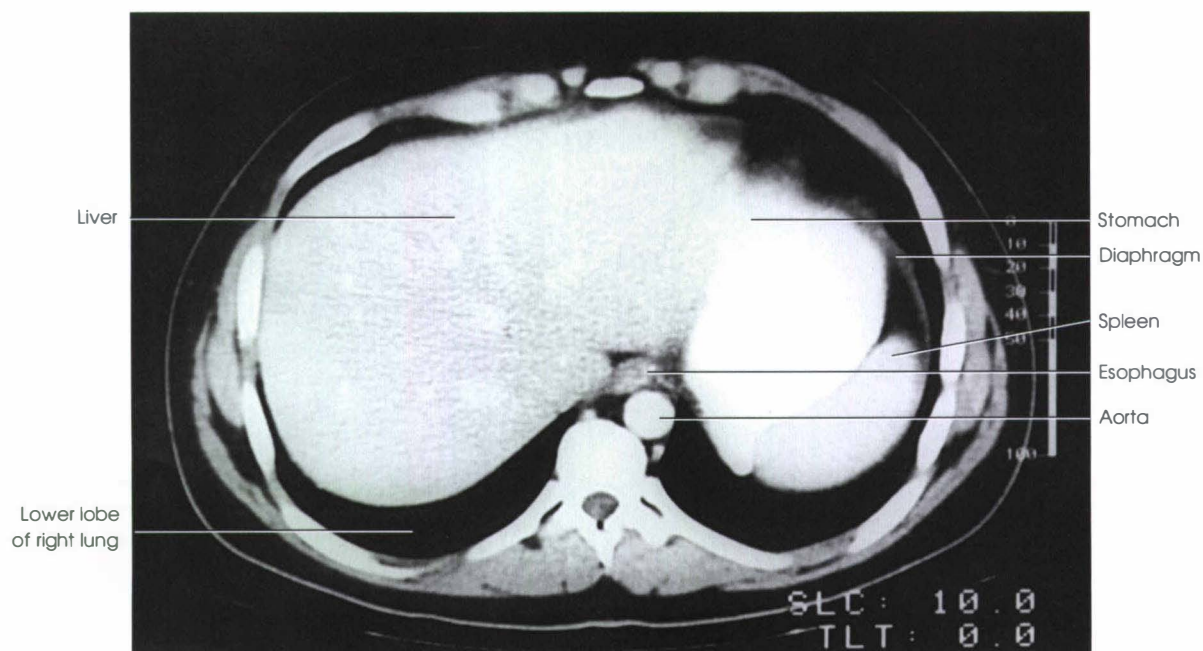


Fig. 27-29 CT image corresponding to Fig. 27-28.

The cadaver section and CT image at the level of T12 demonstrate the relationship between the liver, stomach, and spleen (Figs. 27-30 and 27-31). The cardiac portion of the stomach is located at approximately the T11 level in the anterior aspect of the left upper quadrant, and the pyloric portion normally lies anterior to L2. The spleen, located between the levels of T12 and L1, is in the posterolateral aspect of the left upper quadrant posterior to the *fundus* of the stomach. The liver is generally found between T11 and L3 and occupies the entire right upper quadrant. The right lobe of the liver has two small subdivisions, the *caudate* and *quadrate lobes*, which are bounded by the *gallbladder*, *ligamentum teres*, and IVC. The left lobe of the liver stretches across the midline and into the left upper quadrant. The *suprarenal glands* are normally located superior to the kidney. The right suprarenal gland is found at this level between the liver and the right *diaphragmatic crus*. The left suprarenal gland is medial to the stomach and spleen. The *abdominal aorta* is positioned anterior and to the left of the vertebral column.

The three branches of the *celiac trunk* (hepatic, splenic, left gastric arteries) supply the liver, spleen, pancreas, and stomach with oxygen-rich blood. The *splenic artery* runs a very tortuous course and normally cannot be visualized in its entirety in axial sections. The hepatic artery lies at the porta hepatis, anterior to the IVC. The IVC can be seen in its normal position anterior and to the right of the vertebral column. Branches of the portal vein are seen within the liver, and the main portion of the portal vein is just posterior to the left lobe of the liver.

The muscles of the abdomen are located between the lower rib cage and the iliac crests. This group of muscles includes the *external oblique*, *internal oblique*, and *transverse abdominal muscles*. The two *rectus abdominis muscles* are located on the anterior aspect of the abdomen on either side of the midline and extend from the *pubic symphysis* to the *xiphoid process*. The *psoas muscles* originate from the body of T12 and the transverse processes of the lumbar vertebrae and descend the abdomen lateral to the vertebral bodies. The *quadratus lumborum muscles* are located posterolateral to the psoas muscles through the abdomen.



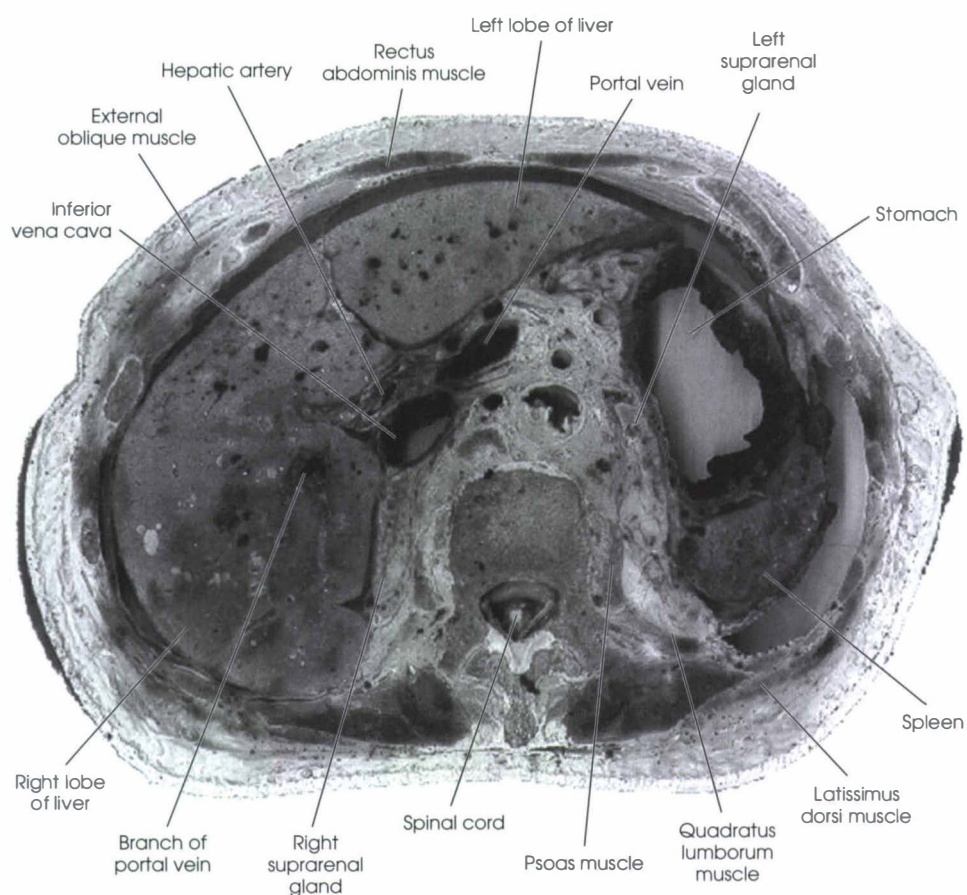


Fig. 27-30 Cadaver section corresponding to level B in Fig. 27-27 at T12.

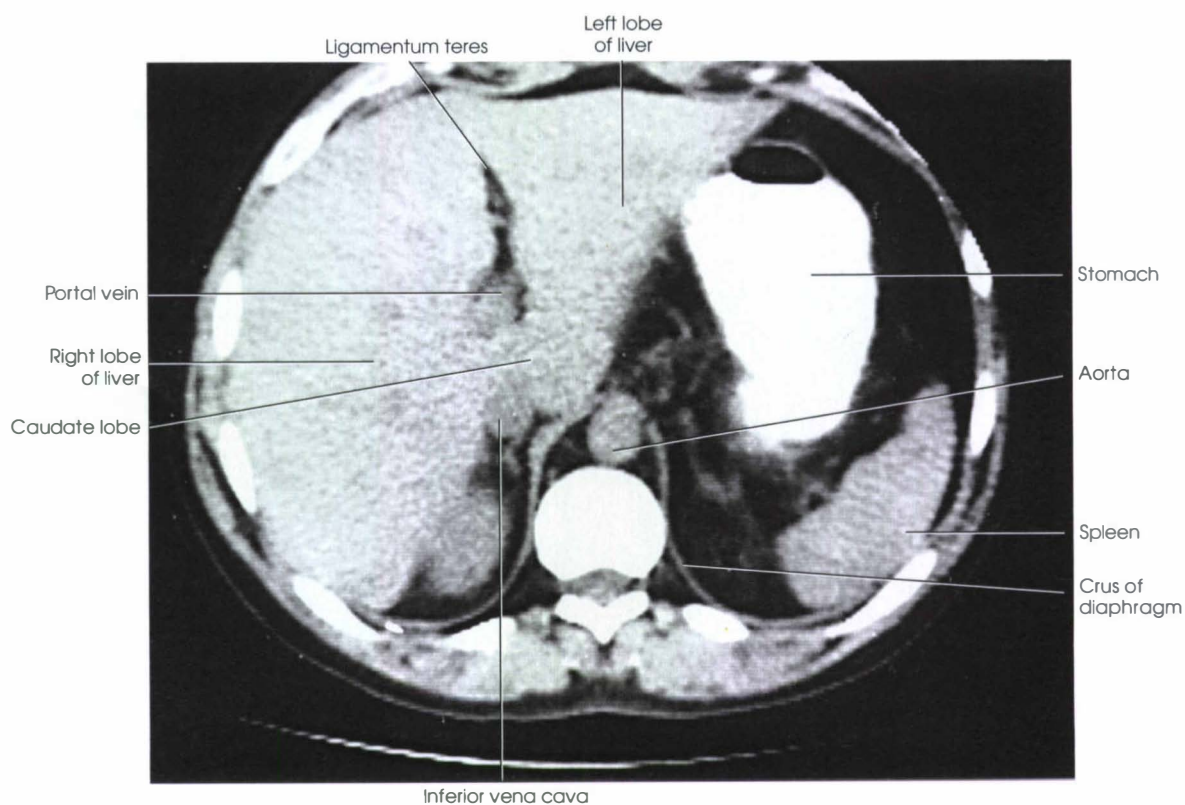


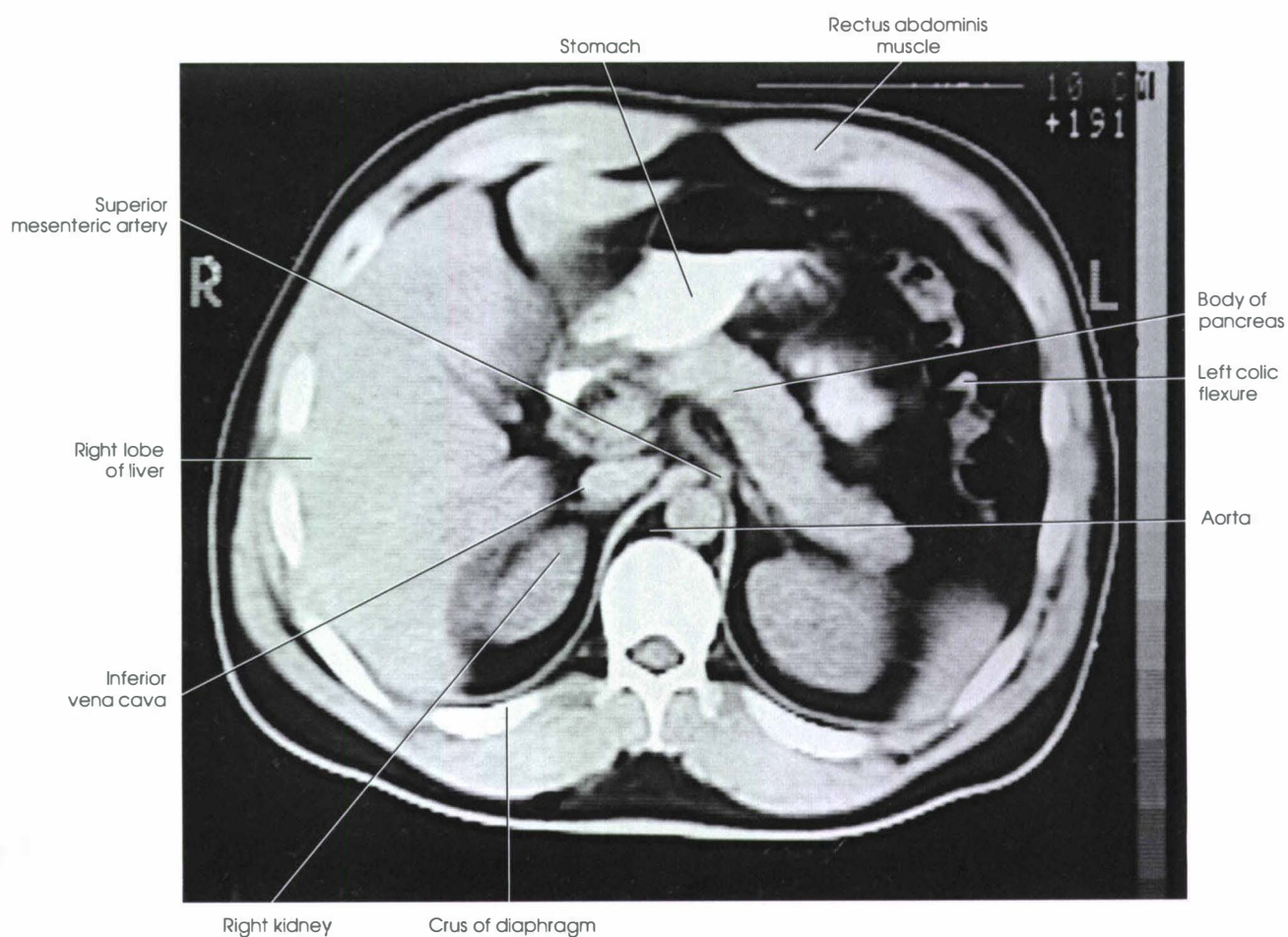
Fig. 27-31 CT image corresponding to Fig. 27-30.

Falciform ligament  
 Left lobe of liver  
 Pyloric region of stomach  
 Pancreas  
 Superior mesenteric artery and vein  
 Stomach (body)  
 Splenic artery  
 Splenic vein  
 Spleen  
 Left kidney  
 Left renal vein  
 Cauda equina  
 Body of L2  
 Right kidney  
 Psoas muscle  
 Inferior vena cava  
 Right lobe of liver  
 Gallbladder  
 Right lobe of liver

**Fig. 27-32** Cadaver section corresponding to level C in Fig. 27-27 at L2.



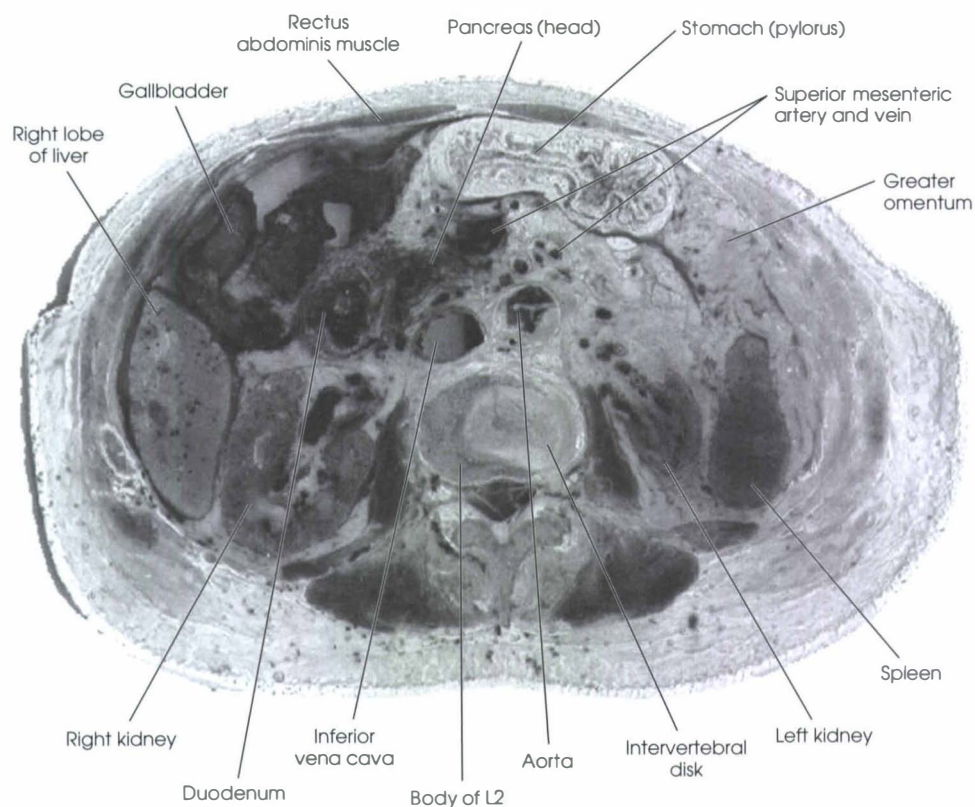
Lateral to the vertebral body are the psoas muscles. The quadratus lumborum muscles are seen between the psoas muscles and the transverse processes of the lumbar vertebrae. The spinal cord normally terminates at the level of L1. Inferior to L1 the spinal nerves, known as cauda equina, are seen within the spinal canal.



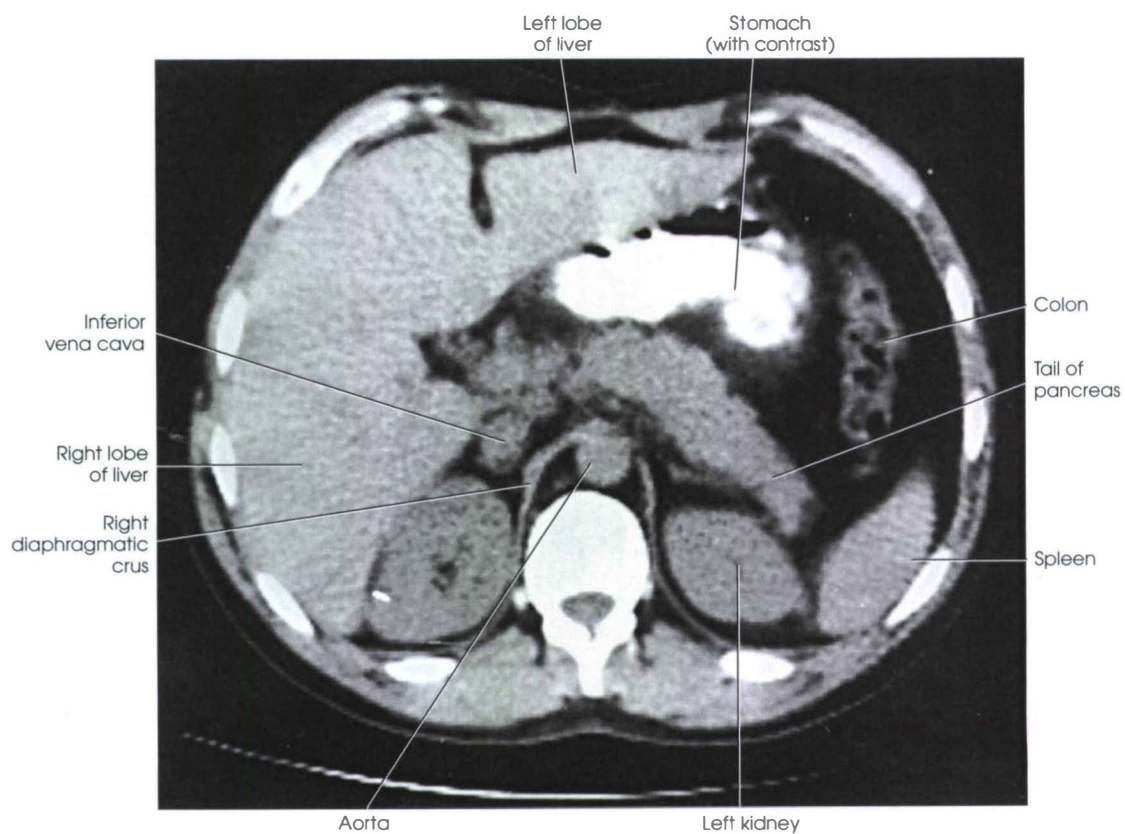
**Fig. 27-33** CT image corresponding to Fig. 27-32. Note the crus (tendinous origin) of the diaphragm surrounding the aorta.



Figs. 27-34 and 27-35 represent the level of the *intervertebral disk* between L2 and L3. At this level the gallbladder is seen lying against the inferior aspect of the liver. The pylorus of the stomach and the second, or descending, portion of the duodenum are anterior in the abdomen. The left colic (splenic) flexure of the colon is seen in the left posterior and lateral aspect of the abdomen in the CT scan. This level demonstrates the *hilum* of each kidney and the head, neck, and body of the pancreas (across the midline). The IVC is seen behind the head of the pancreas. The superior mesenteric vessels and aorta are located posterior to the pylorus of the stomach.



**Fig. 27-34** Cadaver section corresponding to level D in Fig. 27-27 at the interspace between L2 and L3.



**Fig. 27-35** CT image corresponding to Fig. 27-34.

The cadaver section and CT image seen respectively in Figs. 27-36 and 27-37 are at the midsacral level and demonstrate the *wing of the ilium*, the *anterior superior iliac spine (ASIS)*, and the *sacroiliac joints*. At the posterolateral aspect of the ilium the three *gluteal muscles* are visible (on the CT, only two are visible on the cadaver at this level). The *iliacus muscle* is seen lining the internal aspect of the iliac wings near the psoas muscles. The two rectus abdominis muscles are found in the anterior abdomen on both sides of the midline. The *cecum* is found at the right anterior aspect of the pelvic cavity, and the descending colon is seen at the left lateral aspect. Multiple loops of *small intestine* are found throughout this level in the images. The abdominal aorta bifurcates at L4 into the *common iliac arteries*. Each common iliac artery divides at the level of the ASIS into *internal* and *external iliac arteries*. The *internal iliac arteries* tend to be located in the posterior pelvis and branch to feed the pelvic structures. The *external iliac vessels* are found progressively anterior in succeeding inferior sections to become the femoral vessels at the superior aspect of the thigh. The internal and external iliac veins unite inferior to the ASIS to form the common iliac veins, and the IVC is formed anterior to L5 by the junction of the common iliac veins. The common iliac veins are positioned at the anterior aspects of the sacrum with the internal and external iliac arteries lateral to the veins in these images. Through the lower abdomen and at this level the *ureters* are located along the anterior aspect of the psoas muscles and can be seen filled with contrast medium in the CT image (see Fig. 27-37). In the female pelvis the *ovaries* are normally located laterally in the pelvis near the ASIS.



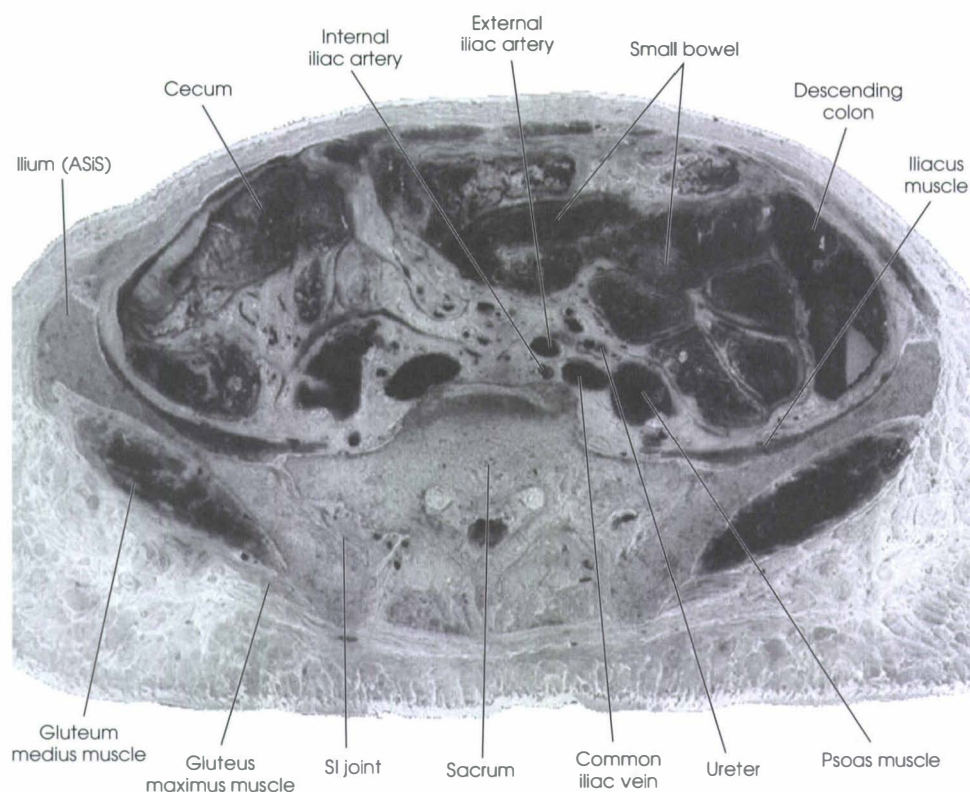


Fig. 27-36 Cadaver section corresponding to level E in Fig. 27-27 at the ASIS.



Fig. 27-37 CT image corresponding to Fig. 27-36.

The cadaver section in Fig. 27-38 is at a level just superior to the pubic symphysis. The CT image in Fig. 27-39 is through the *pubic symphysis*. The *ischial spines*, *acetabula*, *femoral heads*, and *greater trochanters* are visualized. The *coccyx* is seen posterior to the *rectum* in Fig. 27-39. The relationship between the *rectum*, *vagina*, wall of the *bladder*, and superior aperture of the *urethra* is demonstrated from posterior to anterior in the pelvic region. The external iliac vessels are now referred to as the *femoral vessels*, with the name change occurring at the inguinal ligament, which is found between the pubic symphysis and the ASIS. The *iliopsoas muscles* (formed by the junction of the *psoas* and *iliacus* muscles) are found anterior to the femoral heads; the *obturator internus muscle*, with its characteristic right-angle bend, is found medial to the acetabulum.

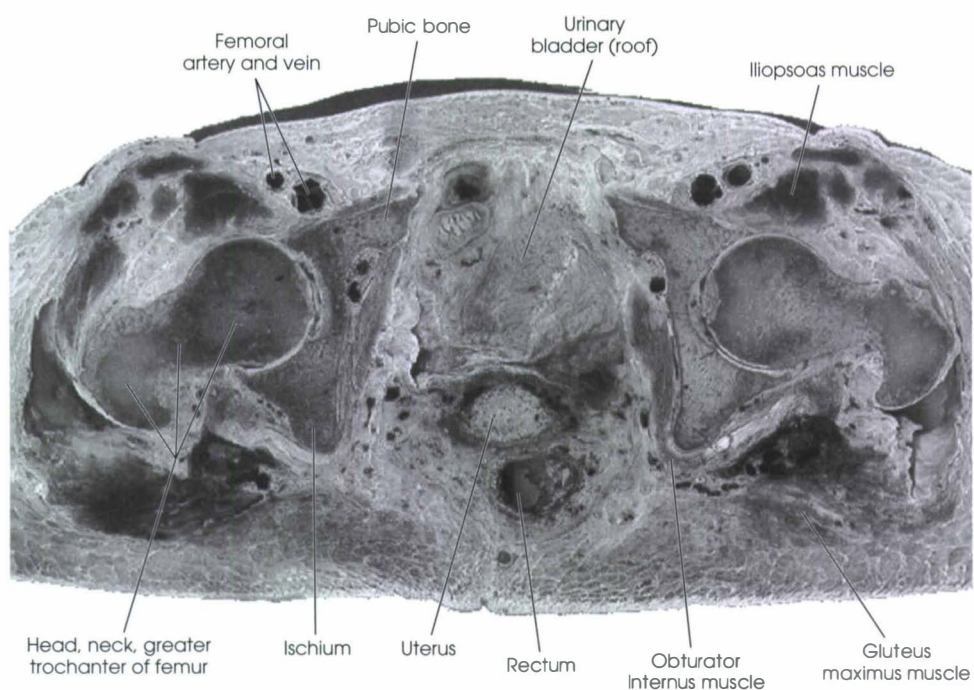


Fig. 27-38 Cadaver section corresponding to level F in Fig. 27-27 at the coccyx (female).

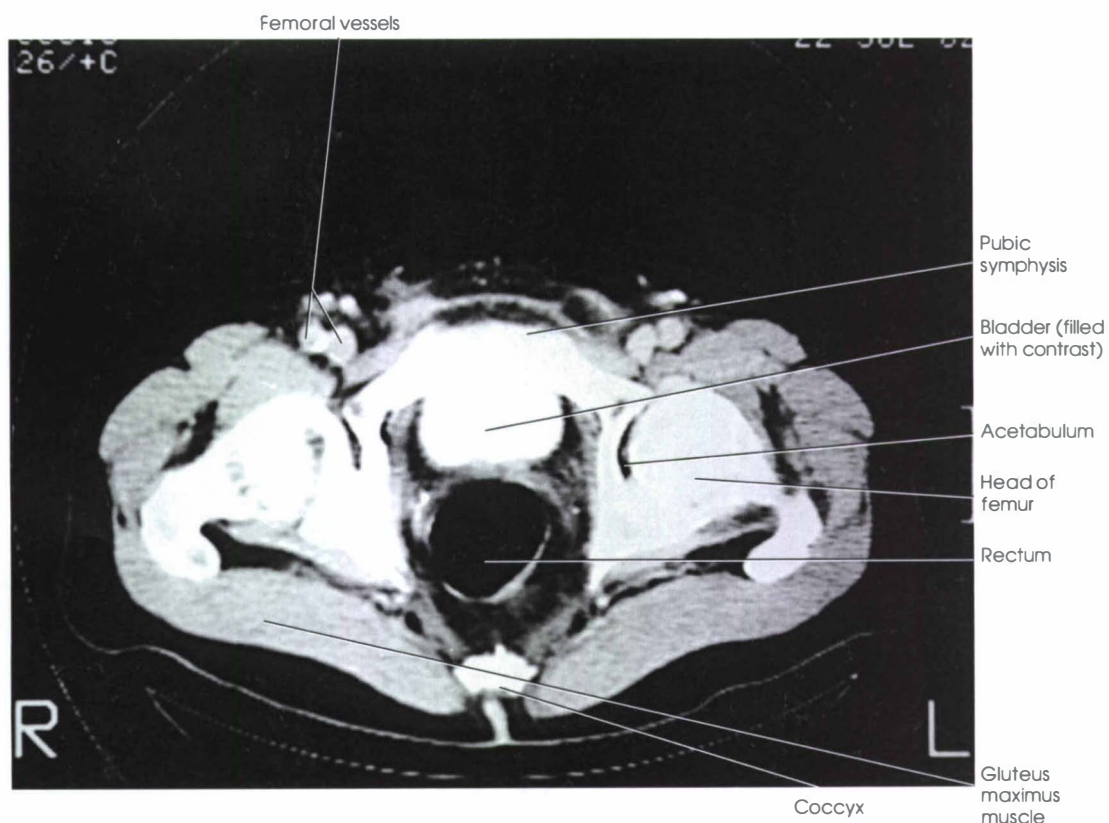
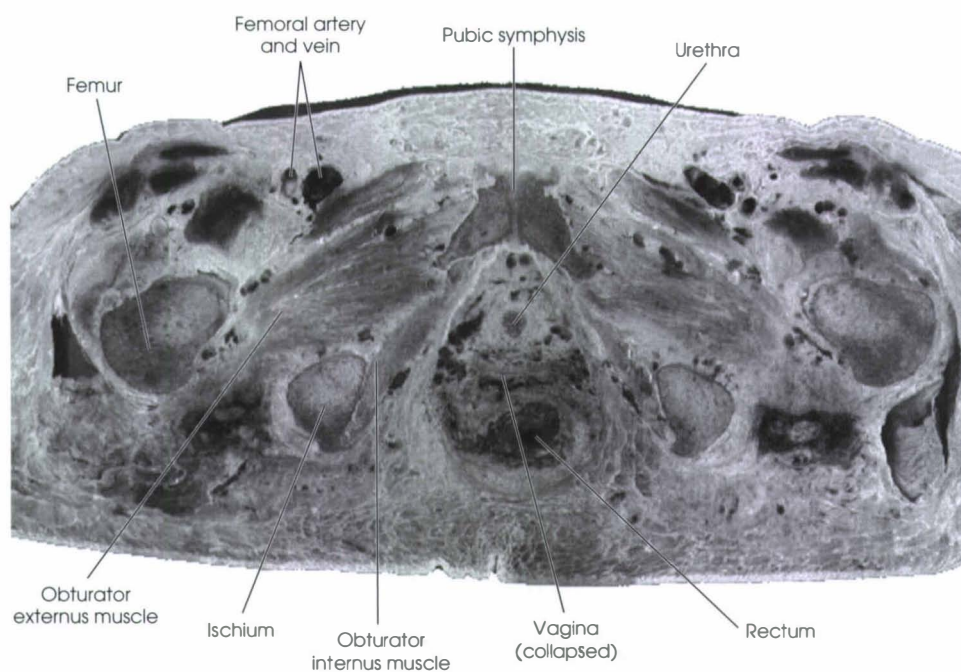


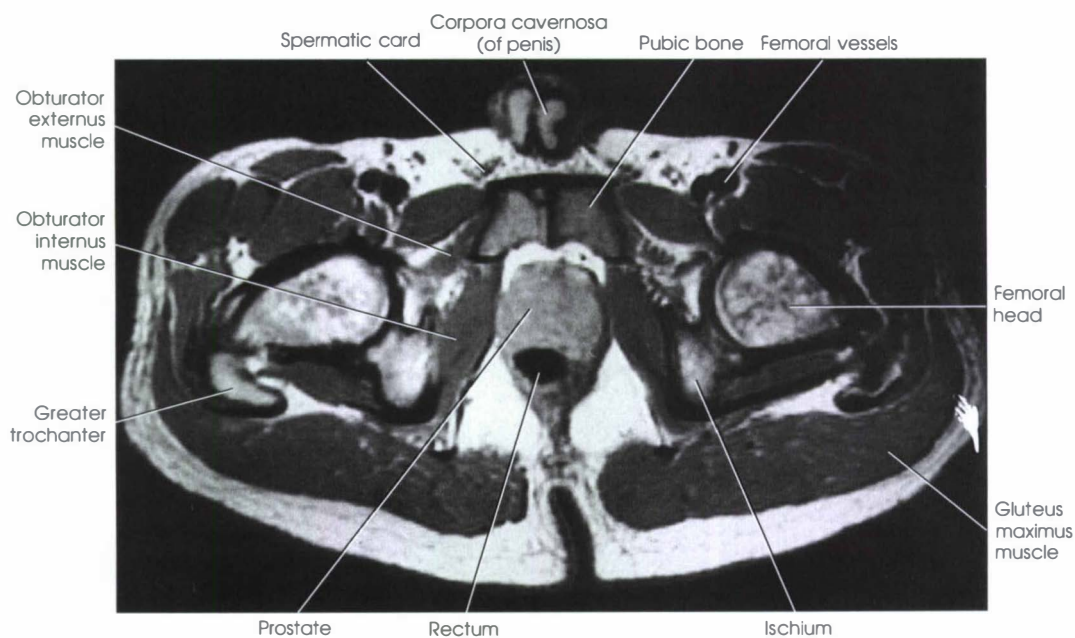
Fig. 27-39 CT image corresponding to Fig. 27-38.



Figs. 27-40 and 27-41 are respectively a female pelvic cadaver section and a male MRI at the same level. These figures highlight structures of the male and female reproductive systems. The cadaver section demonstrates the symphysis pubis, female urethra, the vagina (collapsed), and the rectum from anterior to posterior in the midline. The MRI shows the relationship between the rectum, *prostate gland*, and pubic symphysis and the prostatic portion of the urethra is seen within the prostate. Posterior to the prostate are the *prostatic venous plexus* and *ductus deferens*. The *spermatic cord* contains the ductus deferens and testicular vessels, and it is found superficial and lateral to the pubic symphysis. The circular opening formed by the rami of the pubic and ischial bones is the *obturator foramen*. It is bounded by the *obturator externus* and *obturator internus muscles*. The muscles of the lower limb are anterior to the femur.



**Fig. 27-40** Cadaver section corresponding to level F of Fig. 27-27 at the coccyx (male).



**Fig. 27-41** MRI corresponding to Fig. 27-40.

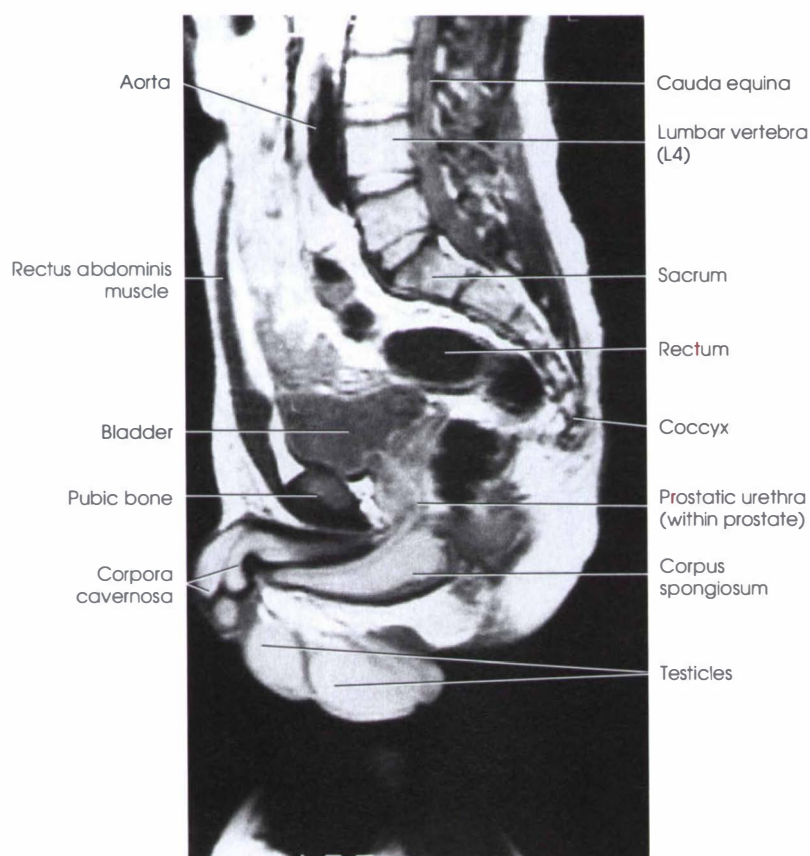


Fig. 27-42 MRI of the abdominopelvic region at the midsagittal plane.

Fig. 27-42 is a sagittal MRI of the structures of the abdomen and pelvis near the midline. L3 through L5, the sacrum, and the coccyx are visualized. The cauda equina is seen descending the spinal canal. Anterior to the vertebral bodies is the distal portion of the abdominal aorta. At the level of L4, the aorta bifurcates to form the right and left common iliac arteries. The large areas of signal void anterior to the sacrum represent the rectum. The bladder is anterior to the rectum and superior to the prostate. The urethra appears faintly, traversing the prostate. The *corpus spongiosum* and *corpora cavernosa* of the penis are inferior and anterior to the pubic symphysis. The right and left *testes* are seen inferior to the *penile* structures. The rectus abdominis muscle extends superiorly from the pubis in the anterior abdominal wall.



A coronal MRI through the femoral heads and greater trochanters is presented in Fig. 27-43. The femoral heads are demonstrated within the *acetabula*. The crests of the ilia are visualized with their associated musculature. The internal surface of the iliac bone is lined by the iliacus muscle. In this image the psoas muscles are seen joining the iliacus muscles to form the iliopsoas muscles. (Iliopsoas muscles are visualized on more anterior sections of the pelvis.) *Gluteus medius* and *minimus* muscles are found external to the iliac bones. The bladder and prostate are seen within the pelvic cavity. Superior to the bladder is a portion of the *sigmoid colon*. The right ductus deferens is found lateral to the neck of the bladder. Between the rami of the pubic bones are the corpus spongiosum and corpora cavernosa. The *scrotum* is seen inferior to the *penis* and between the *gracilis* muscles of the thighs.

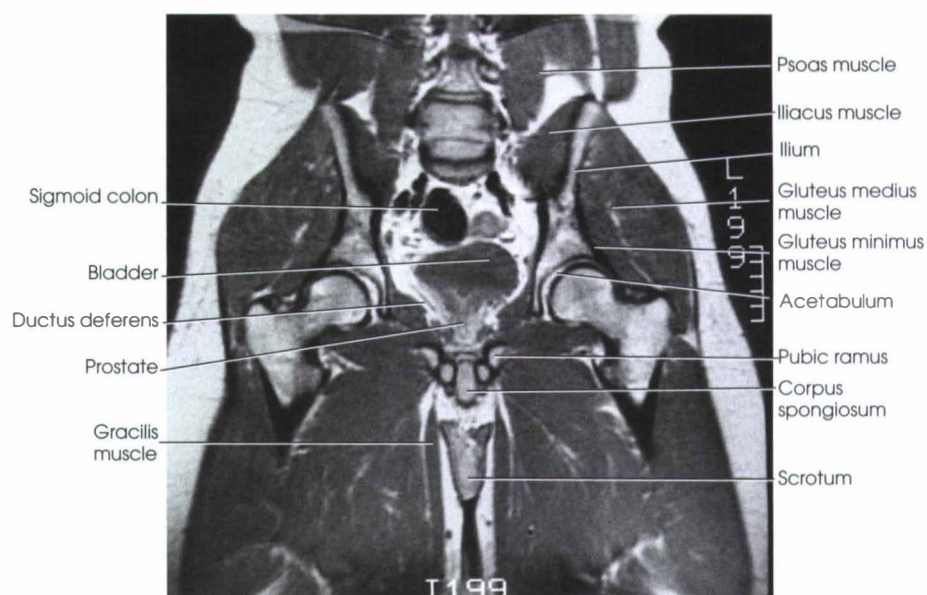


Fig. 27-43 MRI of the abdominopelvic region at the midcoronal plane.

## SUMMARY OF ANATOMY

**Cranial region****Bony structures**

parietal bones  
 frontal bone  
   frontal sinuses  
   orbital roof  
 occipital bone  
   inion  
   internal occipital protuberance  
   foramen magnum  
 temporal bones  
   mastoid air cells  
   petrous ridges  
   external acoustic meatus (EAM)  
   internal auditory canal (IAC)  
 sphenoid bone  
   greater and lesser wings  
   sella turcica  
   optic canal  
   clivus  
   sphenoidal sinuses  
   anterior and posterior clinoids  
 ethmoid bone  
   crista galli  
   ethmoidal air cells  
   perpendicular plate  
   cribriform plate  
   labyrinths  
 zygomatic/malar bones  
 nasal bones  
 maxillae  
   maxillary sinuses  
 vomer  
 mandible  
   coronoid and condyloid processes  
 neck  
 rami

**Cranial region—cont'd****Vasculature**

dural venous sinuses  
   superior sagittal  
   inferior sagittal  
   straight  
   transverse  
   cavernous  
   confluence of sinuses  
 internal jugular veins  
 arterial system  
   internal carotid artery  
   middle cerebral arteries  
   anterior cerebral arteries  
   basilar artery  
   vertebral arteries  
   circle of Willis

**Neurologic structures**

cranial nerves  
   optic  
   olfactory  
   trigeminal  
   acoustic  
 brain  
   lobes (frontal, parietal, temporal, occipital, insula)  
   ventricular system  
   lateral ventricles  
   third ventricle  
   fourth ventricle  
   interventricular foramen  
   cerebral aqueduct  
 cortex, gyri, sulci  
 thalamus  
 pituitary gland  
 basal nuclei  
 lateral fissure  
 longitudinal fissure  
 caudate nucleus  
 falx cerebri and falx cerebelli  
 tentorium cerebelli  
 pineal gland  
 midbrain  
 pons  
 medulla oblongata  
 cerebellum  
   vermis  
   arbor vitae

**Lower face and neck****Bony and cartilaginous structures**

mandible  
 cervical vertebrae  
 thyroid cartilage  
 cricoid cartilage

**Vasculature**

internal and external carotid arteries  
 common carotid arteries  
 vertebral arteries  
 internal jugular veins

**Musculature**

sternocleidomastoid muscles  
 masseter muscles  
 trapezius muscles  
 levator scapulae muscles

**Viscera**

salivary glands (parotid, submandibular, sublingual)  
 tongue  
 pharynx  
 larynx  
 epiglottis  
 thyroid gland  
 trachea  
 esophagus



## SUMMARY OF ANATOMY

### Thorax

#### Bony structures

ribs  
scapula  
coracoid process  
acromion  
spine  
clavicle  
thoracic vertebrae  
sternum  
superior humerus

#### Vasculature

common carotid arteries  
internal jugular veins  
subclavian arteries and veins  
brachiocephalic artery and veins  
aorta  
superior and inferior vena cavae  
pulmonary arteries and veins  
azygos vein

#### Musculature

pectoralis major and minor  
trapezius  
latissimus dorsi  
serratus anterior  
diaphragm

#### Viscera

trachea  
carina  
lungs  
lobes  
apices and bases  
hila  
main bronchi  
heart  
atria  
ventricles  
valves  
esophagus  
thymus

### Abdomen and pelvis

#### Bony structures

lumbar vertebrae  
sacrum  
coccyx  
hip bones  
ilium  
ischium  
pubis  
pubic symphysis

#### Vasculature

aorta  
aortic bifurcation  
celiac trunk  
superior mesenteric artery and vein  
inferior mesenteric artery and vein  
renal arteries and veins  
common iliac arteries and veins  
external iliac arteries and veins  
femoral arteries and veins  
portal vein  
inferior vena cava

#### Musculature

diaphragm  
crura  
external and internal oblique muscles  
transverse abdominis muscles  
rectus abdominis muscles  
psoas major muscles  
iliacus muscles  
gluteal muscles (maximus, medius, minimus)

### Abdomen and pelvis—cont'd

#### Viscera

liver  
lobes (left, right, caudate, quadrate)  
porta hepatis  
spleen  
hilum  
stomach  
fundus  
cardia  
body  
pyloric antrum  
kidneys  
hila  
cortex  
medulla  
perirenal fat  
suprarenal glands  
ureters  
pancreas  
head  
body  
tail  
gallbladder  
small intestine  
duodenum (bulb and C-loop)  
jejunum  
ileum (ileocecal junction)  
large intestine  
cecum  
ascending and descending colon  
right and left flexures  
sigmoid and rectum  
bladder  
urethra  
male reproductive organs  
prostate  
seminal vesicles  
female reproductive organs  
uterus  
vagina



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28

# PEDIATRIC IMAGING

ALBERT AZIZA  
ELLEN CHARKOT

In planning corrective surgery, orthopedic surgeons generally observe the bending images as if looking at the patient's back. The structures to be demonstrated include the uppermost non-wedge-shaped vertebrae and the iliac crests.



## OUTLINE

Principles of pediatric imaging, 170  
Atmosphere, 170  
Approach, 172  
Patient care: psychologic considerations, 175  
Patient care: physical considerations, 176  
Patient care: special concerns, 178  
SUMMARY OF PATHOLOGY, 185  
Protection of the child, 186  
Immobilization: principles and tools, 188  
Common pediatric examinations, 189  
Examinations unique to the pediatric patient, 209  
Overview of advanced modalities, 212  
Conclusion, 217



## Principles of Pediatric Imaging

Understanding that *children are not just small adults* and appreciating that they need to be approached on their level are essential ingredients for successful encounters with children in the imaging department. Many good cooks agree that simply being able to read does not make one a great chef. As with any challenging recipe, the basic steps of pediatric radiography can be explained, but they must also be practiced. Radiographers often lack confidence in two main areas of pediatric radiography—pediatric communication skills and immobilization techniques.

Although pediatric imaging and adult radiography have many similarities, including basic positioning and image quality assessment, some significant differences remain. The way to *approach* the child tops the list of differences. It may help novice pediatric radiographers to think about children of various ages whom they know and to imagine how they would explain a particular radiographic examination to those children. This strategy, along with the descriptions that follow, will prove quite effective. Working successfully with children requires an open mind, patience, creativity, the willingness to learn, and the ability to look at the world through the eyes of a child.

## Atmosphere

The environment in which patients are treated and recover plays a significant role in the recovery process. Research studies have compared the recovery course of patients whose hospital rooms looked out over parks with the recovery course of those whose view was a brick wall. The patients who faced the park had a much shorter hospital stay than the other patients, and they required considerably fewer pain killers. With these differences in mind, the patient care center at the Hospital for Sick Children (Toronto) was designed and built as an atrium (Fig. 28-1). Each patient room receives natural light, either by facing outside or overlooking the atrium, which receives natural light from the glass roof. Although it is easy to see how children can be amused by Miss Piggy and the barnyard animals that fly across the atrium, the environment does not have to be this elaborate to be appreciated by children. Small measures can be taken at relatively little cost to make a child's hospital stay more comfortable.



**Fig. 28-1** Atrium of the Hospital for Sick Children (Toronto), which provides inpatient care and directly related support services.



## WAITING ROOM

Parents of pediatric patients often arrive at the reception desk feeling anxious. They may be worried about what is involved in a procedure because they have not had the specifics explained to them or because they *did not hear* all that was explained to them. They also may be worried about the amount of time the care of their child will take, not to mention the outcome.

Feelings of anxiousness and tension are often transferred from parent to child—the child senses a parent's tension through the parent's tone of voice or actions. A well-equipped waiting room (this does not have to be expensive) can reduce this tension. Children are attracted to and amused by the toys, leaving the parents free to check in or register and ask pertinent questions.

Gender-neutral toys or activities such as a small table and chairs with crayons and coloring pages are most appropriate. (Children should be supervised to prevent them from putting the crayons in their mouths.) Books or magazines for older children are also good investments. The child life department of the hospital can provide advice and recommendations (Fig. 28-2).

## IMAGING ROOM

Time can pass quickly for lengthy procedures if age-appropriate music or videos are available. A child who is absorbed in a video often requires little or no immobilization (other than the usual safety precautions designed to prevent the child from rolling off the table). Charitable and fund-raising organizations are often happy to donate televisions and videocassette recorders (VCRs) for this purpose on request.

Experience has shown that children are less likely to become upset or agitated if they are brought into a room that has been prepared before they enter. This preparation should include placement of the image receptor (IR), approximate centering of the tube to the IR, and placement of all immobilization tools likely to be needed at one end of the table.

Young children are often afraid of the dark. They dislike having the lights turned out but are often comfortable with low levels of illumination. Dimming the lights enough to see the collimator light before the child enters can prevent the need to explain why the lights have to be dimmed. Busy radiographers often turn the lights down without explanation, causing unnecessary anxiety.

After the procedure is complete, the radiographer or other imaging professional should take a moment to emphasize, *even overemphasize*, how helpful the child was and to explain where the child should wait or what the child should do next, *ensuring that the parent is comprehending the instructions*.



Fig. 28-2 Children in waiting area enjoying *normal activity* before being radiographed.

## Approach

### APPROACHING THE PARENT

No discussion of dealing with children is complete without mentioning ways to approach the parent(s). Although children are sometimes brought for medical care by someone other than the parents, for the purposes of this discussion the caregiver is referred to as the *parent*.

In many cases, radiographers find that they are dealing with two patients—the child and the parent. They may wonder to whom they should primarily speak. The answer, however, is easy:

- If the child is capable of understanding, direct the explanation to the child but use age-appropriate language (discussed later). The parents will listen and consequently understand what is expected. Communicating in this way puts the parents more at ease and increases their confidence in the radiographer's skills. They appreciate the fact that their child has been made the focus of attention.
- If the child is too young to comprehend, direct the explanation to the parent, explaining in simple sentences what is going to happen and what is expected of the parent. The importance and value of simple sentences cannot be emphasized enough. People in stress-filled situations do not think as clearly as they normally do, and many parents in this setting are under stress. Successful communication involves the use of short sentences repeated once or twice in a soothing tone.

### Dealing with the agitated parent

When approaching the agitated parent, the radiographer should observe the following guidelines:

- Remain calm and speak in an even tone, remembering that fear and frustration may be the cause of the agitation.
- Use phrases such as "My name is. . . I can identify with how you must be feeling and can appreciate your concern," followed by "Let me explain to you what is happening."
- If possible, escort the parent to a nearby room or office to continue the explanation. This can avoid an unwanted scene in the waiting room.

### Parent participation

The degree of parent participation depends on several factors:

1. The general philosophy of the department
2. The wishes of the parent and patient
3. The laws of the province or state regarding radiation protection

The advantages of parental participation can be great for everyone concerned—patients, parents, radiographers, and departmental administrators. Experience has shown that both parents should have the basic procedure explained to them. However, it is advisable that only *one* parent be present in the imaging room. The presence of both parents often causes the room to become crowded; moreover, it is distracting and can actually lengthen the procedure. Many provincial or state laws permit only one additional person in the room, and this serves nicely as a rationale when the radiographer explains the policy to parents. Posting signs to this effect in strategic locations also can be helpful.

Parental participation is insisted on by many parents and advocated by many pediatric radiographers for the following reasons:

1. The parent can watch the child if the attention of the radiographer or radiologist is directed to the equipment or the fluoroscopic monitor.
2. The radiographer may need to leave the room.
3. The parent can assist with immobilization if needed (where permitted).
4. The parent who witnesses an entire procedure has little room for doubt about professional conduct.

This last point illustrates a benefit to parents, as well as medical personnel. The parent's presence ensures that no action, explanation, or question is misinterpreted by the child or adolescent. At the same time, the parent can take comfort in seeing that the child is being cared for in a professional manner. Although parental participation is perhaps less controversial now than it was in the past, radiographers can put the situation in perspective by imagining themselves in the position of parents and asking whether they would want to be present. With increasing public knowledge and the ever-present threat of litigation, parents are participating in more procedures.

Informed parents, whether physically present in the imaging room or not, can usually help to explain the procedure to the child. Some hospitals and commercial organizations have prepared pamphlets describing procedures and answering many commonly asked questions.

In some situations, parental presence is not advised. For example, some children are further agitated by their parents' presence, or some parents may find certain procedures too disturbing, such as those performed in the angio/interventional suites.

Whenever parents are in the room during a radiographic exposure, they should be protected from scatter radiation. They should also be given lead gloves if their hands will be near the primary radiation beam.

## APPROACHING THE CHILD

Naturally, good communication is essential to obtaining maximum cooperation. Thus children should be spoken to at their level in words that they can understand. Fortunately, this is not as difficult as learning a new language, and it can be made even easier if the radiographer keeps a few strategies in mind:

- Greet the patient and parent in the waiting area with a smile.
- Bend down to talk to the child at the child's eye level.
- Take a moment to *introduce yourself and ensure that you have the correct patient*; then state briefly what you are going to do.
- Suggest, rather than ask, the child to come and *help* you with some pictures. This *firm, yet gentle* approach avoids creating the idea that the child has a choice. After all, the patient may be tempted to be emphatic and say *no*.
- Use sincere *praise*. This is a powerful motivator, no matter what the age of the patient. Praise for young children (3 to 7 years old) should be immediate. Children have short attention spans and often expect to receive rewards immediately. The reward should be linked directly to the task that has been well done. Use phrases such as "You sat very still for me, thank you" or "You took a nice, big breath in for that picture, and I am going to ask you to do it again for the next one."
- When the outcome will be the same, *give children an option*: "Would you like Mom to help lift you up on the table, or may I help you?" or "We have two pictures to do. Which would you like first—the one with you sitting down or the one with you lying down?"

- Employ distraction techniques. As radiographers develop confidence in basic radiography skills and adapting these skills for children, they find themselves able to engage in *chatter* and *distraction techniques*, thus making the experience as pleasant as possible for the child. Ask the child about brothers, sisters, pets, school, or friends—the topics are limitless. As homework, watch a few popular children's cartoons. Communication is improved when the radiographer can build rapport with a child, and learning a few more distraction techniques is helpful.
- Answer all questions truthfully—regardless of their nature. Maintaining honesty is crucial in all communications with children. Confidence and credibility built by the previous strategies can be lost if the truth is withheld. The secret is not to volunteer information too early or dwell on unpleasanties.

The child's age should greatly influence the approach. Children are unique individuals with unique social styles, of course, but the following guidelines may still prove helpful.

### Infants

The basic needs of infants to the age of 6 months are warmth, security, and, of course, nourishment. They do not make an appreciable distinction among caregivers. They are often calmed by the use of a pacifier or soother. As they get older, they become attached to familiar objects, which they should be allowed to keep with them. Because infants are easily startled, care should be taken to minimize loud stimuli.

### Children 6 months to 2 years old

Children between 6 months and 2 years of age are particularly fearful of pain, separation from their parents, and limitation of their freedom of movement. This helps to explain why they are very disturbed by immobilization. Unfortunately, children in this age group usually require the most assertive immobilization techniques. Experience has shown it is less disturbing to children to be well immobilized than to have a number of adults in lead aprons trying to hold them in the correct positions.

Although radiographers should be knowledgeable in the art of immobilization for children in this age group (particularly 2-year-olds), one of the most valuable forms of immobilization is natural sleep. The challenge, of course, is to complete the entire radiographic sequence without waking the child. This can be done by carefully transferring the child to the table and taking care to maintain warmth, comfort, and safety.

Parental participation is especially valuable with this age group, as it is with children between the ages of 2 and 4 years. Radiographers can easily pick up tips for communicating with children by taking cues from parents as they explain procedures to their children. Parents are also helpful because they can act as "baby-sitters" during the procedure.

**NOTE:** Chest radiography must be performed while children are awake. Because respirations are generally shallow during sleep, it is not possible to obtain an adequate degree of inspiration.



### Children 2 to 4 years old

Preschoolers can test the power of the radiographer's imagination. They are extremely curious—their favorite question is “Why?” They enjoy fantasy and may readily cooperate if the situation is treated like a game or distraction techniques are used. The following strategies can be useful:

- Give explanations at the child's eye level by bending down or by sitting the child on the radiographic or scanner table.
- Take a moment to show the child how the collimator light works and let the child turn it on (Fig. 28-3)—for a child this is as much fun as pressing the buttons in an elevator.
- Use the camera analogy to describe the x-ray tube, taking care to explain that the tube may move sideways but will never come down and touch the child.
- Avoid any unnecessary equipment manipulation.
- Encourage the child gently as the child attempts to cooperate—then praise the cooperation.

Children between 2 and 4 years of age can be verbally and physically aggressive. A child who is having a tantrum will not respond to games and distraction techniques. Making the procedure as short as possible through the use of practiced and kind, yet effective, immobilization techniques is the best approach. Young patients generally calm down quickly when they are back in their parents' arms or resume the activity they were involved in before the examination.

### The 5-year-old

The 5-year-old has typically reached a time that is rich in new experiences. Reactions can differ widely, depending on how at ease the child feels with a given environment. Children in this age group generally want to perform tasks correctly, and they enjoy mimicking adults. When a 5-year-old feels confident, that child will act like a 6-, 7-, or 8-year-old; however, when afraid or worried, that same child may cling to parents and become reticent and uncooperative. Constant reassurance and simple explanations help in such moments.

### School-age children 6 to 8 years old

For the radiographer who is not accustomed to working with children, the perfect group to start with is the 6- to 8-year-olds. These children are generally accommodating and eager to please. They are modest and embarrass easily, so their privacy should be protected. These children are the easiest age group with which to communicate; they appreciate being talked through the procedure, which gives them less time to worry about their surroundings or the procedure itself. Anatomic landmarks are easy to locate for positioning, and body habitus evens out nicely—the “big belly” of the toddler disappears. From an imaging standpoint, the bones are maturing, with the increased calcium content enhancing subject contrast (Fig. 28-4).



**Fig. 28-3** The radiographer should make an introduction to the child and show the child how the collimator light is used. The child can be allowed to turn on the light.



**Fig. 28-4** Child properly positioned and shielded for a lateral elbow radiograph.

## Adolescents

Image is important to preteens and adolescents. Although they are better able to understand the need for hospitalization, they are upset by interference in their social and school activities. They are particularly concerned that as a result of the injury they may not be able to return to their preinjury state. These patients require, and often demand, explicit explanations. Health care workers should not be surprised by the frankness of their questions and should be prepared for some discussion.<sup>1</sup>

Adolescents want to be treated as adults, and the radiographer must exercise judgment in assessing the patient's degree of maturity. The radiographer should become familiar with the local statutes regarding consent in order to understand when children are deemed to be responsible for themselves.<sup>2</sup>

*Sensitive issues*, such as the possibility of pregnancy in the postpubescent girl, must be approached discreetly. Honest responses are more likely to be elicited if the girl is alone with the radiographer (i.e., the parent is not present), and the following guidelines are observed:

- Preface the questioning by stating that information of a sensitive nature needs to be obtained for radiation safety.
- Ask the 10-, 11-, 12-, or 13-year-old girl if she has started menstruating. If the response is affirmative, continue by saying that a slightly more sensitive question needs to be asked. Then ask if there is any possibility of pregnancy.
- Simply but tactfully ask girls 14 years and older if there is any chance of pregnancy. Judging from the patient's expression and response, decide how to continue.
- Differing levels of maturity call for different explanations. If necessary, apologize for the need to ask sensitive questions and assure the patient that the same questions are asked of all girls of this age.
- Follow the questioning with an explanation that it is unsafe for unborn babies to receive radiation.
- If possible, have the questioning performed by a female.

## APPROACHING PATIENTS WITH SPECIAL NEEDS

### Children with physical and mental disabilities

The radiographer should consider age when approaching children with physical and mental disabilities. Children over 8 years old with disabilities strive to achieve as much autonomy and independence as possible. They are sensitive to the fact that they are less independent than their peers. The radiographer should observe the following guidelines:

- Direct communication toward the child first. All children appreciate being given the opportunity to listen and respond. Like any patients, these children also want to be talked to rather than talked about.
- If this approach proves ineffective, turn to the parents. As a general rule the parents of these patients are present and can be very helpful. In strange environments younger children may trust only one person—the parent. In that case the medical team can gain cooperation from the child by communicating through the parent. Parents often know the best way to lift and transfer the child from the wheelchair or stretcher to the table. Children with physical disabilities often have a fear of falling and may want only a parent's assistance.
- After introducing yourself, briefly explain the procedure to the child.
- Place the wheelchair or stretcher parallel to the imaging table, taking care to explain that you have locked the wheelchair or stretcher and will be getting help for the transfer. These children often know the way they should be lifted—*ask them*. They can tell you which areas to support and which actions they prefer to do themselves.

Finally, children with spastic contractions are often frustrated by muscle movements that are counterproductive to the intended action. Gentle massage should be used to help relax the muscle, and a compression band should be applied to maintain the position.

Communicating with a child who has a mental disability can be difficult, depending on the severity of the disability. Some patients react to verbal stimuli. Loud or abrupt phrases can startle and consequently agitate them.

## Patient Care: Psychologic Considerations

Although pediatric patients have many of the same psychologic characteristics as adults, some factors are worthy of mention to better prepare the radiographer for interactions with children and their parents.

### EMERGENCY PATIENT

When an accident happens, emotions run high, thought processes are clouded, and the ability to rationalize is often lost. For the parents of the child who has been injured, another powerful factor is often involved—guilt. As parents try to absorb information about the child's condition, they also ask themselves how they could have let the accident happen. Dealing with these questions often prevents parents from hearing or understanding all that is being explained. In addition, fearing that permanent damage has been done, the child can feel extremely traumatized by a relatively minor injury. The radiographer should observe the following guidelines in dealing with emergency patients and their parents:

- Greet the patient and parents, and then describe the procedure using short, simple, and often-repeated sentences.
- Remember that when patients and parents speak with a tone of urgency and frustration, this usually stems from fear. Maintaining a calm perspective in these situations can ensure a smooth examination.
- Increase the level of confidence the parents and child have in your abilities with frequent reassurance presented in a calming tone. (The *reassurance* referred to here is reassurance that the radiographer knows how to approach the situation, not reassurance that all will be well with respect to the injury.)
- In emergency examinations, as with any other examination, ensure that only one caregiver is giving the child instructions and explanations. (Caregivers include parents, nurses, doctors, and radiographers, all of whom may be present.) Much greater success is achieved when only one person speaks to the child.
- After completing the procedure, ensure that you have the parents' attention. Speaking slowly, give clear instructions about where to wait and what to expect.

<sup>1</sup>Wilmot DM, Sharke GA: *Pediatric imaging for the technologist*, New York, 1987, Springer-Verlag.

<sup>2</sup>Torres LS: *Basic medical techniques and patient care in imaging technology*, ed 5, Philadelphia, 1997, Lippincott-Raven.



## OUTPATIENT

Generally speaking, outpatients and their parents are easier to approach than inpatients. For the radiographer who has had little experience with children, these are among the best patients with whom to begin. Outpatient visits are frequently a form of progress report, and patients are usually ambulatory and relatively healthy. For the most part, parents are calm because they are not dealing with the emotions of an emergency situation or perhaps the tension or fear that the parents of inpatients can experience. However, they can become agitated if kept waiting too long, which unfortunately happens often in the outpatient clinical setting.

## INPATIENT

A child must usually be very sick to be admitted to a hospital. Children often become acutely ill in a much shorter period than adults. However, they generally heal quicker than adults, which decreases the length of the hospital stay. The stresses the child experiences involve fear and separation from parents, family, and friends. It also is a stressful time for the parents who, while worrying about their child's health, must often juggle time for work and for taking care of other family members. By understanding that these responsibilities weigh heavily on parents' minds and by remembering to provide reassurance and simple explanations, the radiographer can make the child's visit to the imaging department easier.

## Patient Care: Physical Considerations

### GENERAL MEASURES

Depending on the level of care being provided, children may arrive in the imaging department with chest tubes, IV infusions (including central venous lines), colostomies, ileostomies, or urine collection systems. Usually these children are inpatients, but in many instances outpatients (particularly in interventional cases) arrive in the department with various tubes in situ (e.g., gastrostomy or gastrojejunostomy tube placements). The radiographer must be aware of the purpose and significance of these medical adjuncts and know the ways to care for the patient with them (see Figs. 28-43 and 28-44).

The competent and caring radiographer takes note of the following:

1. What are the specific instructions regarding the care and management of the child during the child's stay in the department?
2. Will a nurse or another health care professional accompany the child?
3. Will physical limitations influence the way the examination is performed?

Many inpatients are on a 24-hour urine and stool collection routine. Therefore medical personnel who change diapers on these patients should save the old diaper for the ward/floor personnel to weigh or assess.

Hospital policy and the availability of nursing staff within the imaging department determine the amount of involvement the radiographer has with the management of IV lines. The radiographer must be able to assess the integrity of the line and must know the measures to take in the event of problems.<sup>1</sup>

<sup>1</sup>Torres LS: *Basic medical techniques and patient care in imaging technology*, ed 5, Philadelphia, 1997, Lippincott-Raven.



## ISOLATION PROTOCOLS AND STANDARD BLOOD AND BODY FLUID PRECAUTIONS

Prevention of the spread of contagious disease is of primary importance in a health care facility for children. Microorganisms are most commonly spread from one person to another by human hands. *Careful hand washing* is the single most important precaution, but unfortunately, it is often the most neglected. In addition, all equipment that comes in contact with the radiographer and patient during isolation cases must be washed with an appropriate cleanser.

The premise of standard blood and body fluid precautions is that *all blood and body fluids* are to be considered *infected*. The Centers for Disease Control and Prevention recommend that health care workers practice blood and body fluid precautions when caring for all patients. These precautions are designed to protect both patients and medical personnel from the diseases spread by infected blood and body fluids. All blood and body fluids, including secretions and excretions, must be treated as if they contain infective microorganisms. Working under this assumption, personnel can protect themselves not only from patients in whom a known infective organism is present but also from the unknown. The management of patients in isolation varies according to the type of organism or preexisting condition, the procedure itself (some can alternatively be performed with a mobile unit), and hospital/departmental policies. Decisions regarding when to bring an infectious patient to the department also often depend on the condition of other patients who may be in the vicinity. For example, patients with *multiresistant organisms* should not be close to immunocompromised patients.

The radiographer should follow all precautions outlined by the physician and nursing unit responsible for the child. Respiratory, enteric, or wound precautions for handling a patient are usually instituted to protect staff members and other patients. Isolation procedures are instituted to protect a patient from infection. Protective isolation is used, for example, with burn victims and patients with immunologic disorders. The protective clothing worn by staff members may be the same in either situation, but the method of discarding it will be different.<sup>1</sup>

<sup>1</sup>Torres LS: *Basic medical techniques and patient care in imaging technology*, ed 5, Philadelphia, 1997, Lippincott-Raven.

## Patient Care: Special Concerns

As with most pediatric examinations, a team approach produces the best results. Cooperation among all caregivers and the child provides for a smooth examination. A few special situations that deserve individual mention are discussed in the following sections.

### PREMATURE INFANT

One of the greatest dangers facing the premature and sometimes the full-term neonate is *hypothermia* (below normal body temperature). *Thermoregulation*, the balance of heat losses and gains, is crucial to the care and survival of the premature infant. The sources of heat loss—evaporation, convection, conduction, and radiation—are greater in the preterm infant. Premature babies have a greater surface area in comparison to body mass. Furthermore, they are not capable of storing the fat needed for warmth, and they have increased metabolic rates.

So that hypothermia does not occur, premature infants should be examined within the infant warmer or isolette whenever possible. Therefore general radiography must be performed with a portable or mobile unit. (See Chapter 30 for a discussion on *Mobile Radiography*.) The radiographer should take great care to prevent the infant's skin from coming in contact with IRs. Covering the IR with one or two layers of a cloth diaper (or equivalent) works well; however, the material should be free of creases because these produce significant artifacts on neonatal radiographs.

When the premature infant is brought to the imaging department for gastrointestinal (GI) procedures or various types of scans, the radiographer should observe the following guidelines:

- Elevate the temperature in the room 20 to 30 minutes before the arrival of the child. The ambient temperature of the imaging room is usually cool compared with the temperature of the neonatal nursery.
- When raising the temperature is impossible, prepare the infant for the procedure while the infant is still in the isolette and remove the infant for as brief a period as possible.
- Use heating pads and radiant heaters to help maintain the infant's body temperature; however, these adjuncts are often of limited usefulness because of necessary obstructions such as the image intensifier. If heaters are used, position them at least 3 feet from the infant.
- Place large bags of IV solutions, prewarmed by soaking in a sink of warm water, beside the infant to serve as small hot water bottles.
- Monitor the infant's temperature throughout the procedure, and keep the isolette plugged in to maintain the appropriate temperature.

Because of the risk of infection to infants in the neonatal intensive care unit (NICU), most units insist on adherence to isolation protocols such as gowning and hand washing.

**NOTE:** *Neonatal* refers to newborn. Although premature babies comprise the highest percentage of patients in NICUs, all of the infants in these units are not necessarily premature. Full-term babies experiencing distress are also cared for in NICUs.

The radiographer must take care when positioning an infant from the NICU. Many of these infants can tolerate only minimal handling without their heart rates becoming irregular.

### MYELOMENINGOCELE

A *myelomeningocele* is a *congenital* defect characterized by a cystic protrusion of the meninges and the spinal cord tissue and fluid. It occurs as a result of spina bifida, a cleft in the neural arches of a vertebra. It can be recognized by fetal ultrasonography at the seventeenth or eighteenth week of gestation. Myelomeningoceles may cause varying degrees of paralysis and hydrocephalus. The higher the location of the myelomeningocele, the worse the neurologic symptoms.

Patients with myelomeningoceles are cared for in the prone position. Therefore, whenever possible, radiographic examinations on these patients should be performed using the prone position until the defect has been surgically repaired and the wound healed. The primary imaging modalities used in the investigation and follow-up care of myelomeningoceles include ultrasonography, computed tomography (CT), and magnetic resonance imaging (MRI).

## OMPHALOCELE AND GASTROSCHISIS

An *omphalocele* is a congenital defect that resembles an enormous umbilical hernia. Omphaloceles are covered in a thin, translucent, membranous sac of peritoneum, and their contents include bowel and perhaps liver. *Gastroschisis* is a similar condition in which a portion of bowel herniates through a defect near the naval. The difference is that in gastroschisis the bowel is not included within a sac.

In both omphalocele and gastroschisis the herniated abdominal contents must be kept warm and moist. This is especially important with gastroschisis. A responsible physician or nurse should be present when patients with these conditions are examined radiographically, because they become rapidly hypothermic.

## EPIGLOTTITIS

*Epiglottitis is one of the most dangerous causes of acute upper airway obstruction in children and must be treated as an EMERGENCY.* Its peak incidence occurs in children between the ages of 3 and 6 years. Epiglottitis is usually caused by *Haemophilus influenzae*, and the symptoms include acute respiratory obstruction, high fever, and *dysphasia* (inability to swallow or difficulty in swallowing). When epiglottitis is clinically suspected, the radiographer observes the following steps:

- **Insist** that the patient be accompanied by and transported **into** the radiographic room with the responsible physician. The patient must be supported in the upright position with an emergency physician monitoring the airway at all times.
- **Do not proceed with the necessary lateral radiograph of the nasopharynx or soft tissues of the neck without the presence of the physician.**
- Perform the single upright lateral image **without moving the patient's head or neck.**
- Take extreme care to ensure the child does not panic, cry, or become agitated.

## OSTEOGENESIS IMPERFECTA

*Osteogenesis imperfecta*, a disease characterized by brittle bones, is often referred to by its abbreviation, *OI*. Because the approach and management need to be altered significantly in the imaging department to accommodate patients with *OI*, radiographers should be aware of this commonly used abbreviation. Children with *OI* are prone to spontaneous fractures or fractures that occur with minimal trauma. Although *OI* can vary in severity, patients with this disease need to be handled with extreme care by an experienced radiographer.

Children with *OI* are almost always accompanied by a key caregiver—usually a parent. Experience has shown that these patients are best handled with a team approach in an unhurried atmosphere. The team is comprised of the patient, parent (caregiver), and radiographer, with the radiographer observing the following guidelines:

- Constantly reassure the parent and patient that every part of the procedure will be explained before it is attempted.
- For the best results, explain the desired position to the parent in simple terms. For example, “the knee needs to point to the side” for a lateral image. Then allow the parent to do the positioning.
- Ask the older child for advice on the way the child should be moved or lifted.
- If possible, take the radiographs with the child in the bed or on the stretcher. This is often possible, given the patient's small physical stature.

*Practical tip:* It is wise to evaluate the technical factors by checking the first radiograph before proceeding with the rest of the series. (Generally speaking, the technical factors can be halved.) The radiographer should remember that an introduction and a few moments of explanation and reassurance that the radiograph will be done using a team approach can ensure a smooth examination in most *OI* patients.



### SUSPECTED CHILD ABUSE

Although no *universal* agreement exists on the definition of child abuse, the radiographer should have an appreciation of the all-encompassing nature of this problem. *Child abuse* has been described as “the involvement of physical injury, sexual abuse or deprivation of nutrition, care or affection in circumstances, which indicate that injury or deprivation may not be accidental or may have occurred through neglect.”<sup>1</sup> Although diagnostic imaging staff members are usually involved only in cases in which physical abuse is a possibility, they should realize that sexual abuse and nutritional neglect are also prevalent.

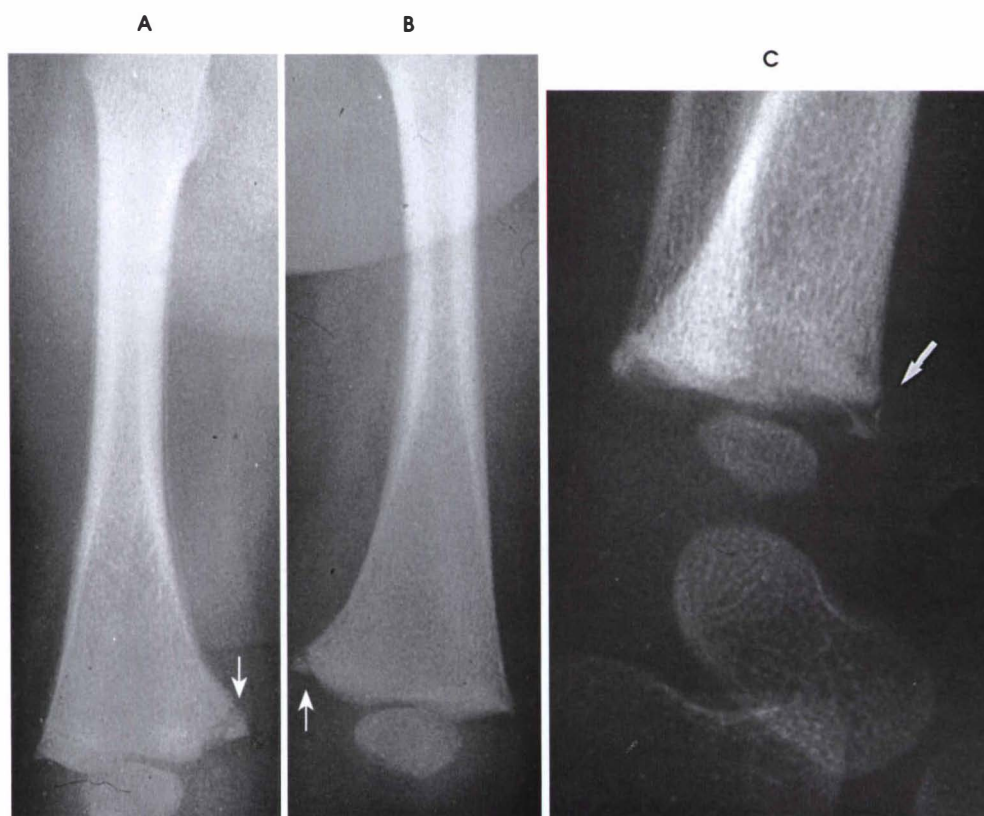
<sup>1</sup>Robinson MJ: *Practical pediatrics*, ed 2, New York, 1990, Churchill Livingstone.

It is mandatory in all provinces and states in North America for health care professionals to *report suspected cases* of abuse or neglect. The radiographer, while preparing or positioning the patient, may be the first person to suspect abuse or neglect (Fig. 28-5). The first course of action for the radiographer should be to consult a radiologist (when available) or the attending or responsible physician. After this consultation the radiographer may no longer have cause for suspicion, because some naturally occurring skin markings mimic bruising. *If the radiographer's doubts persist, the suspicions must be reported to the proper authority, regardless of the physician's opinion.* Recognizing the complexity of child abuse issues, many health care facilities have developed a multidisciplinary team of health care workers to respond to these issues. Radiographers working in hospitals have access to this team of physicians, social workers, and psychologists for the purposes of reporting their concerns; others are advised to work through their local Children's Aid Society or appropriate organization.



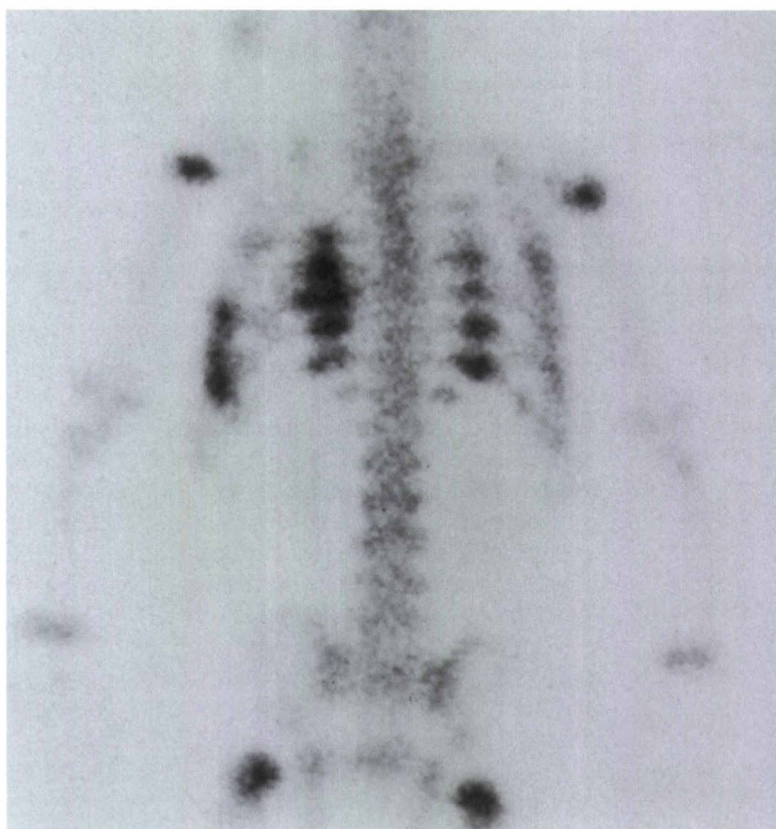
**Fig. 28-5** 7-year-old with loop marks representative of forceful blows by a looped belt.

Plain image radiography, often the initial imaging tool, can reveal characteristic radiological patterns of skeletal injury. Clear evidence of posterior rib fractures, corner fractures, and “bucket-handle” fractures of limbs are considered *classic indicators* of physical abuse (Fig. 28-6). All imaging modalities can and do play a role in the investigation of suspected child abuse. After plain radiography, nuclear medicine is often the next investigative tool of choice (Fig. 28-7). Computed tomography with 3D reconstruction has contributed to differentiating cases of actual abuse from accidental trauma (Fig. 28-8). The presence of numerous fracture sites at varied or multiple stages of healing can also indicate long-term or ongoing abuse. These cases are often viewed by nonradiologic staff members (e.g., lawyers), as well as imaging professionals. Therefore evidence of injury must be readily apparent, especially since pediatric fractures at an early age can remodel totally over a period of time, thus providing no clear evidence of earlier fractures.

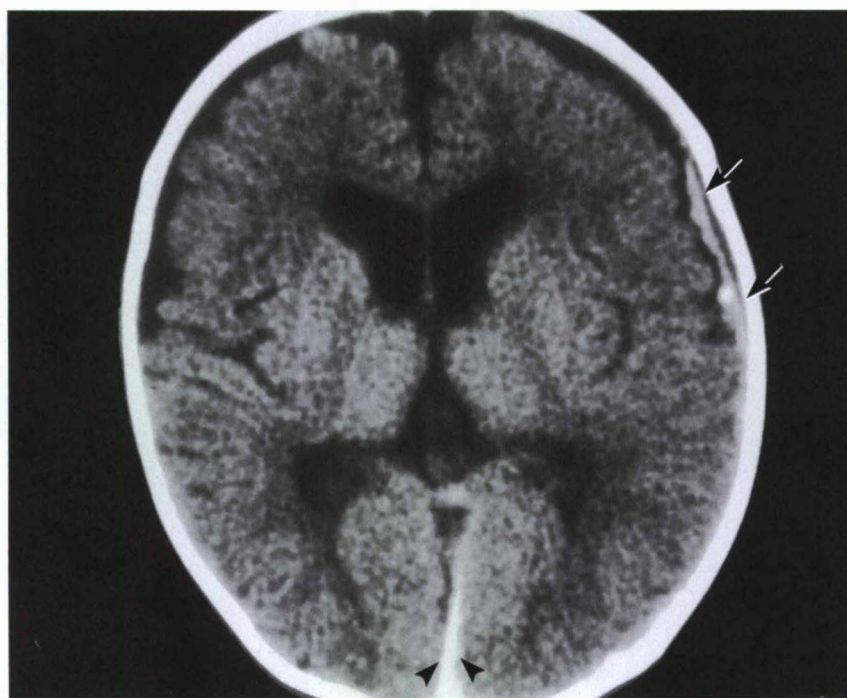


**Fig. 28-6** Radiographs demonstrating physical abuse. Left and right corner fractures (arrows, **A** and **B**) and bucket-handle fractures (arrow, **C**) are considered classic indicators of physical abuse in children. The bucket handle appearance is subtle and demonstrated only if the “ring” is seen on profile (arrow).





**Fig. 28-7** Delayed image of bone scintigraphy (nuclear medicine) demonstrating focal increased uptake in the posterior lower six ribs bilaterally in a linear fashion indicative of child abuse.



**Fig. 28-8** CT axial non-contrast image of the brain demonstrating a hyperdense crescent-shaped collection in the subdural space consistent with acute hemorrhage (*arrows*). There is also evidence of old resolving subdural hematomas (*arrowheads*). This is characteristic of child abuse.

The radiographer's role is to provide physicians with diagnostic radiographs that *demonstrate bone and soft tissue equally well*. Referring physicians depend on the expertise of the diagnostic imaging service for the detection of physical abuse, and radiologists are able to estimate the date of the injury based on the degree of callous formation or the amount of healing.

The radiographer observes the following guidelines when dealing with a case of possible child abuse:

- Give careful attention to exposure factors and the recorded detail demonstrated for limb radiography. Imaging systems yielding high detail are recommended for cases of suspected child abuse because the associated skeletal injuries are often very subtle (Fig. 28-9).

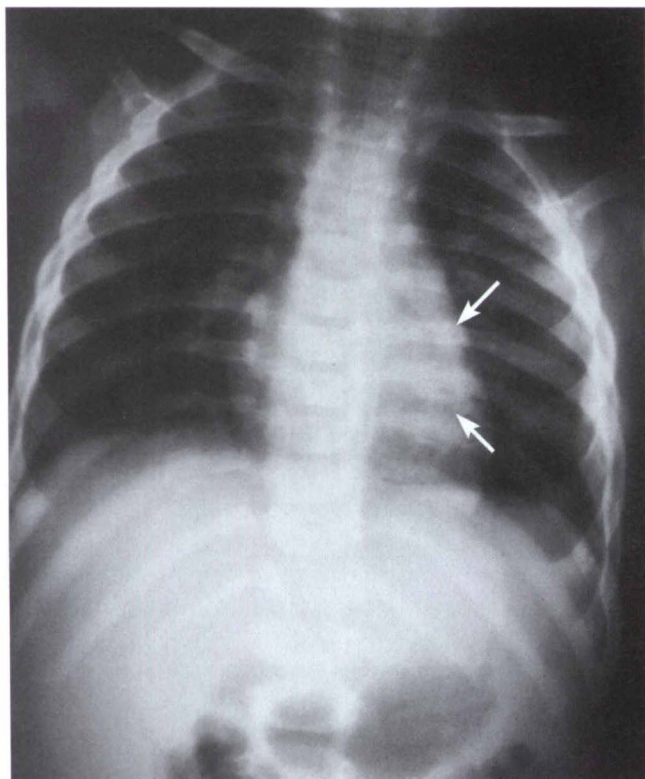


Fig. 28-9 Chest radiograph showing different stages of healing posterior rib fractures (arrows).

- Performing a *babygram*—a 35 × 43 cm (14 × 17 inch) IR of the entire baby—should be avoided because the resultant images are of reduced diagnostic quality. Distortion because of improper centering, scatter, and underexposure or overexposure of the radiograph all play a part in the degradation of the image. Babygrams are no longer considered an acceptable imaging protocol for the investigation of child abuse. Instead *skeletal surveys* with *multiple images of individual areas* should be performed using appropriate centering points, collimation, and technical factors. The following guidelines were developed based on routines performed at the Hospital for Sick Children in Toronto:

AP Skull

Lateral Skull

AP Complete Spine

Lateral Complete Spine

AP Both Humeri

AP Both Radii and Ulnae

PA Both Hands and Wrists

AP Pelvis

AP Both Femora

AP Both Tibiae and Fibulae

AP Both Feet

AP Chest for Ribs

Lateral Chest for Ribs

All images must be performed separately with exposure factors adjusted to maximize recorded detail. Visualization of joints is an essential component of the study. Chest x-rays are done primarily for visualizing ribs and therefore can be done with the patient lying on the table utilizing lower kVp and Bucky grid.

- Although it may be difficult to do, give the parents of these children the same courtesy as any other parent. Remember that the parent who is present may not be responsible for the injuries. Deal with the parent in a nonjudgmental manner aimed at not jeopardizing further relations between the parent and health care providers.



## SUMMARY OF PATHOLOGY: PEDIATRIC IMAGING

Condition	Radiographic Finding
Congenital Club Foot	Abnormal twisting of the foot, usually inward and downward
Congenital Hip Dysplasia	Malformation of the acetabulum causing displacement of the femoral head
Cystic Fibrosis	Disorder associated with widespread dysfunction of exocrine glands, abnormal secretion of sweat and saliva, and accumulation of thick mucus in the lungs
Fracture	Disruption in the continuity of bone
Greenstick	Incomplete fracture of a bone
Torus or Buckle	Impacted fracture with bulging of the periosteum
Hirschsprung's or Congenital Aganglionic Megacolon	Absence of parasympathetic ganglia, usually in the distal colon, resulting in the absence of peristalsis
Hyaline Membrane Disease or Respiratory Distress Syndrome	Underaeration of the lungs due to a lack of surfactant
Intussusception	Prolapse of a portion of the bowel into the lumen of an adjacent portion
Legg-Calvé-Perthes Disease	Flattening of the femoral head due to vascular interruption
Osgood-Schlatter Disease	Incomplete separation or avulsion of the tibial tuberosity
Osteomalacia or Rickets	Softening of the bones due to a vitamin D deficiency
Pyloric Stenosis	Narrowing of the pyloric canal causing obstruction
Scheuermann's Disease or Adolescent Kyphosis	Kyphosis with onset in adolescence
Slipped Epiphysis	Proximal portion of femur dislocated from distal portion at the proximal epiphysis
Tumor	New tissue growth where cell proliferation is uncontrolled
Ewing's Sarcoma	Malignant tumor of bone arising in medullary tissue
Osteochondroma	Benign bone tumor projection with a cartilaginous cap
Osteosarcoma	Malignant, primary tumor of bone with bone or cartilage formation
Wilm's Tumor	Most common childhood abdominal neoplasm affecting the kidney



## Protection of the Child

### PROTECTION FROM INJURY

The diagnostic imaging department is responsible for ensuring that children neither injure themselves nor are injured during their stay in the department. Emphasis on quality assurance and risk management dictates that many hospitals (and, consequently, radiology departments) perform routine safety inspections to take a proactive stance in minimizing the potential for harm. These inspections are often performed by a two-person team that includes: (1) the supervising or charge radiographer and (2) a frontline worker, whose input is vital because the worker uses the equipment on a daily basis. The following guidelines are observed:

- To *avoid the possibility of injury*, supervise children while they are in the department or being transported to and from the department. Some departments clearly delineate, in their policy and procedure manuals, safety precautions to be carried out while patients are in the imaging room. Such policies relate to the use of Velcro or compression bands designed to prevent patients from rolling from the imaging table (see Figs. 28-10 and 28-16).

- Regularly inspect all immobilization tools to ensure that they are maintained in working order. Experienced radiographers should instruct all novice pediatric radiographers in proper immobilization techniques, and novice radiographers' practices should be observed by senior or supervising radiographers.
- In the event of an injury, however minor, file a report documenting the specifics of the incident and the actions taken. Some departments require that reports be filed even in the event that there was *potential* for an injury to occur.

### PROTECTION FROM UNNECESSARY RADIATION

The conscientious radiographer can do much to protect children from exposure to unnecessary radiation. Radiographers should remember that bone marrow, active in the formation of blood cells, is distributed throughout the pediatric skeleton and that tissue damage is associated with ionizing radiation. Radiographers should observe the following steps:

- Direct efforts toward *proper centering and selection of exposure factors, precise collimation, and appropriate use of filters* (where required), which all contribute to safe practice.



**Fig. 28-10** Three tools frequently used in pediatric immobilization: (left to right) a Velcro band, often called a Bucky or body band; a strip of reusable Velcro; and a “bookend.”

- Use *strategic placement of gonadal and breast shielding* and employ *effective immobilization techniques* to reduce the need for repeat examinations.
- Instead of the AP projection, use the PA projection of the thorax and skull to reduce the amount of radiation reaching the breast tissue and lens of the eye respectively.
- During radiography of the upper limbs *protect the upper torso of all children.*
- Employ diagonal placement of small gonadal aprons along the thorax and abdomen to protect the sternum and gonads of infants and toddlers during supine radiography.
- Have older children wear child-size full lead aprons or adult aprons. (See Common Pediatric Examinations, Limb Radiography, later in this chapter.)

Radiographers in supervisory and management positions have added responsibilities. In addition to ensuring that the previously described practices are followed, supervising radiographers should take into account the clinical needs of the radiologist and follow the ALARA (As Low As Reasonably Achievable) principle of radiation exposure when developing technique charts or programming exposure consoles. Pediatric imaging poses conflicting demands on imaging protocols. High kilovolt (peak) (kVp) is desired to keep the milliamperes-seconds (mAs) low (thereby reducing the absorbed dose), but low mA values can present *quantum mottle* problems in the radiographic examination of small body parts, specifically pediatric limbs and neonatal chests. For acceptable diagnostic quality, relatively high resolution is needed. Practically speaking, these needs are often met by the development of a multispeed film-screen combination or *computed radiography* (CR) system. Slow-speed systems are used to demonstrate small parts (limbs and neonatal chests), and faster speeds are used for procedures involving the spine, abdomen, and GI tract. The least confusing approach is to purchase one type of film and *screens of varying speeds*, when a film-screen system is used. The IRs are then color coded along their outer edges, and the user can be directed to a corresponding color-coded chart to select the appropriate combination.

Used judiciously by experienced and knowledgeable personnel, CR can reduce the radiation dose (see Chapter 34). This technique significantly shortens the time needed to perform the procedure and optimizes or tailors the images to suit individual patient requirements. As a result of increased familiarity with the power of window-level adjustments in CT (see Chapter 33) and MRI (see Chapter 36) radiologists have developed a deeper appreciation and acceptance of the digital format. Automatic, laser-printed spot images in GI barium studies are a common general application of *image intensifier-based digital radiography*. Pulsed fluoroscopy with “last image hold” also reduces patient dose and length of examination. Furthermore, the ability to transmit the digital image directly to a laser printer to produce hard copies or to PACS (picture archive and communication system) saves valuable radiographer time. This savings often allows the radiographer to spend more time with the patient or to assist the next child sooner.

*A cautionary note:* The fact that digitally acquired images can be “postprocessed,” thereby correcting some exposure errors, does not negate an important truth—*images of proper density are achieved by proper positioning*. The anatomy to be demonstrated must be in proper alignment with the photocell or ionization chamber.

## Immobilization: Principles and Tools

Perhaps the two most successful tools for pediatric radiography are *effective immobilization* and *good communication skills*. Respected pediatric radiographers approach patients and parents with kindness and take care to maintain patient comfort throughout the procedure.

Naturally, a willingness to cooperate on the child’s part allows for more *passive*, less aggressive immobilization techniques. *Reassurance*, *praise*, and conversational *distraction* are the three ingredients of successful communication. Reassurance is perhaps second only to sleep as the best passive immobilization technique. A sleeping child who is moved gently, kept comfortable and warm, and not startled by sudden or loud noises often remains asleep throughout the procedure. However, as previously noted, all chest images must be taken while the child is awake, because the rate of respiration is too shallow during sleep to provide full inspiration images.

Despite effective communication, it is often necessary to restrain children during radiography. If immobilization is not handled appropriately, difficulties can arise for the radiographer, patient, and parent. Immobilization should never become a traumatic, torturous event for the child, and no immobilization technique should cause harm to the child. Experienced radiographers should teach novice pediatric radiographers how to *carefully* restrain a child. A radiographer’s lack of experience, coupled with the parent’s and child’s fear, can often lead to frustration on *everyone’s* part. With practice, the radiographer can keep patients both comfortable and immobilized with a minimum of frustration.

The radiographer can prevent a great deal of frustration by using the communication strategies described at the beginning of this chapter and applying some *practiced* immobilization techniques. It is important to remember that the parent (presuming one is present) can do only one job. For example, a parent who assists with the radiographic examination of her 2-year-old’s forearm can help only by holding the humerus and the hand; the radiographer or some other staff member has the tasks of immobilizing the other arm and both legs.

Aside from the regular sponges and sandbags, three tools frequently used in pediatric immobilization deserve mention. They are the Velcro compression band (sometimes referred to as a Bucky or body band), a strip of reusable Velcro, and a “bookend” (see Fig. 28-10). These devices are effective for the immobilization of children, although their applications are not limited to pediatric radiography.

Other tools, such as the Pigg-o-stat (Modern Way Immobilizers, Clifton, Tenn.) and the octagonal infant immobilization cradle, are described in the following sections.



## Common Pediatric Examinations

### CHEST RADIOGRAPHY

The most common radiographic procedure performed in hospitals and clinics is of the chest. Radiologists agree that for most diagnostic chest radiographs in pediatric patients, upright images yield a great deal more information than supine radiographs. It is, however, important to know the way to achieve diagnostic quality in both positions. Regardless of body position, accurate diagnosis depends on high-quality images made with short exposure times to reduce motion. *Expiratory images can lead to erroneous radiologic interpretations.* Therefore images acquired on *maximal inspiration* are crucially important for accurate diagnosis. Well-positioned, non-rotated radiographs are also essential for proper diagnosis because even minor degrees of rotation can significantly distort the normal anatomy.

### Upright radiograph on the newborn to 3-year-old

The many challenges of obtaining upright images include preventing motion and rotation, freeing the lung fields of superimposition of humeri and scapulae, and obtaining a good inspiratory radiograph. Various methods of immobilization are used to achieve these images, often with somewhat mixed results. Fortunately these challenges are easily met with the use of a pediatric positioner and immobilization tool called the *Pigg-o-stat* (Fig. 28-11). Although the Pigg-o-stat is primarily used for chest radiography, other applications include upright abdominal images and radiography of the thoracic and lumbar spine.

The Pigg-o-stat is composed of a large support base on wheels, a small adjustable seat, and Plexiglas supports called sleeves. These sleeves come in two sizes. The seat, sleeves, and “turntable” base rotate as a unit to facilitate quick positioning from PA to lateral projections. Although some physicians do not favor use of the Pigg-o-stat (for aesthetic reasons and because of the possibility of sleeve artifacts), the device has been shown to be one of the safest and most versatile restraining methods available for chest and upright abdominal radiography.

### Communication with parents

The Pigg-o-stat requires explanation for parents unfamiliar with its use. The radiographer should offer an explanation similar to this: “Doctors prefer chest x-rays to be performed with the child in the upright position. To help your child remain still, we have the child sit on this little seat. These plastic supports fit snugly around the child’s sides and keep the arms raised. The device looks funny, and your child will probably cry, but this is usually an expression of frustration about being confined. The crying actually helps to obtain a good x-ray image because at the end of a cry your child will take a big gasp of air. At that moment the exposure will be taken.”

A complete explanation is worthwhile and essential. The parent can be shown how to help place the child on the seat by guiding the feet in. Then the parent can assist by holding the arms above the child’s head.

Radiographers should realize that positioning a child in a Pigg-o-stat is a *two-person job*. Radiographers can safely take children out of the Pigg-o-stat without assistance, but an extra pair of hands is needed in the initial positioning. The properly instructed parent is generally willing and able to assist.



**Fig. 28-11** Position for PA chest radiograph. The Pigg-o-stat (Modern Way Immobilizers, Clifton, Tenn.) is a pediatric positioner and immobilization tool. The IR is held in the metal extension stand.

## Method

The following steps are observed:

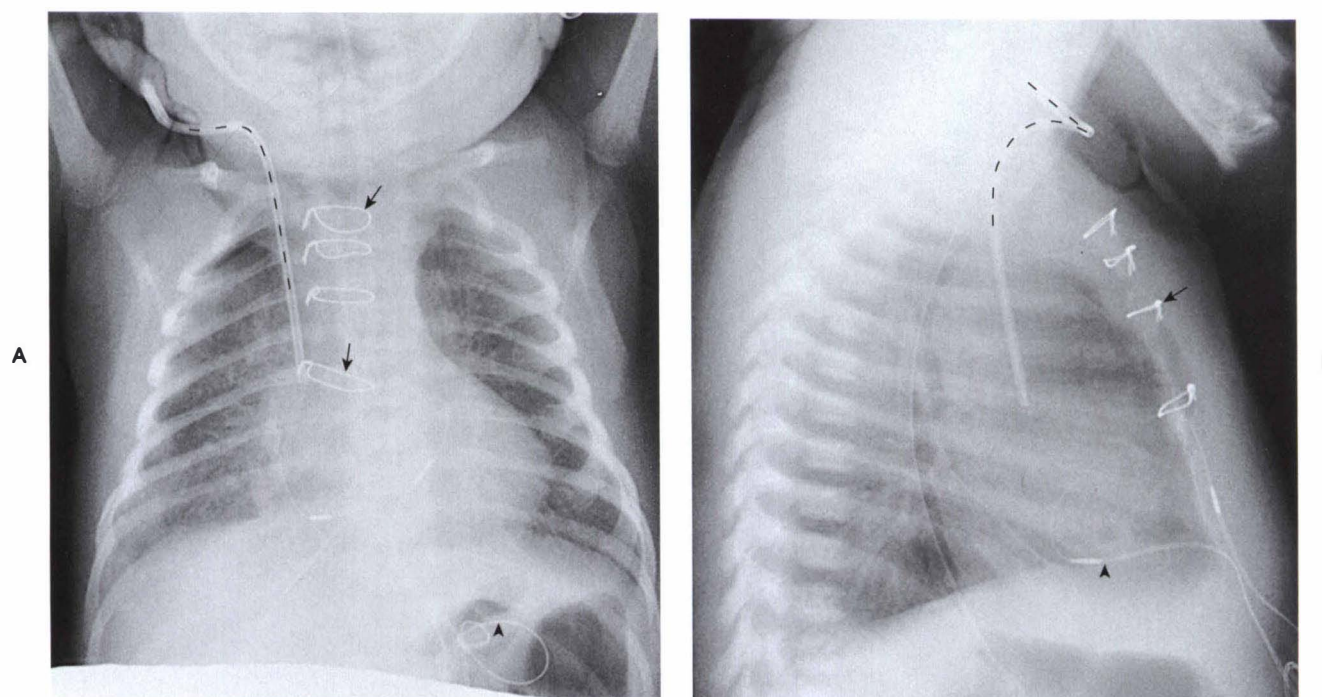
- Have the patients undress completely from the waist up, so that after the patient is positioned, the ribs are visible on inspiration.
- Choose the appropriate sleeve size. Sleeves should fit snugly, which often requires Velcro strips or adhesive tape wrapped around the base of the sleeves (see Fig. 28-11).
- Adjust the seat height to approximately the correct level. The seat is at the correct height if, when the patient is sitting up straight, the face fits in the contours or cutout portions of the sleeves.

This one-step positioning, in which the child is sitting straight on the seat with the arms raised evenly above the head, ensures motionless and nonrotated images (Fig. 28-12). The orientation of the room (i.e., where the chest stand or IR holder is located relative to the control panel) and the image requested determine how well the radiographer can see the child's thorax to ensure that the exposure is made during inspiration. The radiographer can detect inspiration by doing the following (listed in decreasing order of reliability):

1. Waiting for the end of a cry—the child will take a big gasp of air
2. Watching the abdomen—the child's abdomen will extend on inspiration
3. Watching the chest wall—the ribs will be outlined on inspiration
4. Watching the rise and fall of the sternum

## Centering and collimation

The central ray for both PA and lateral projections is directed to the level of T6-T7, but the collimated field should extend from and include the mastoid tips to just above the iliac crests. Inclusion of the mastoid tips demonstrates the upper airway; narrowed or stenotic airways are a common source of respiratory problems in pediatric patients. By collimating just above the crests of the ilia, the radiographer can include the inferior costal margins. A significant number of children arrive in the imaging department with long lung fields resulting from hyperinflation. Noted examples include patients with cardiac disorders and asthma.



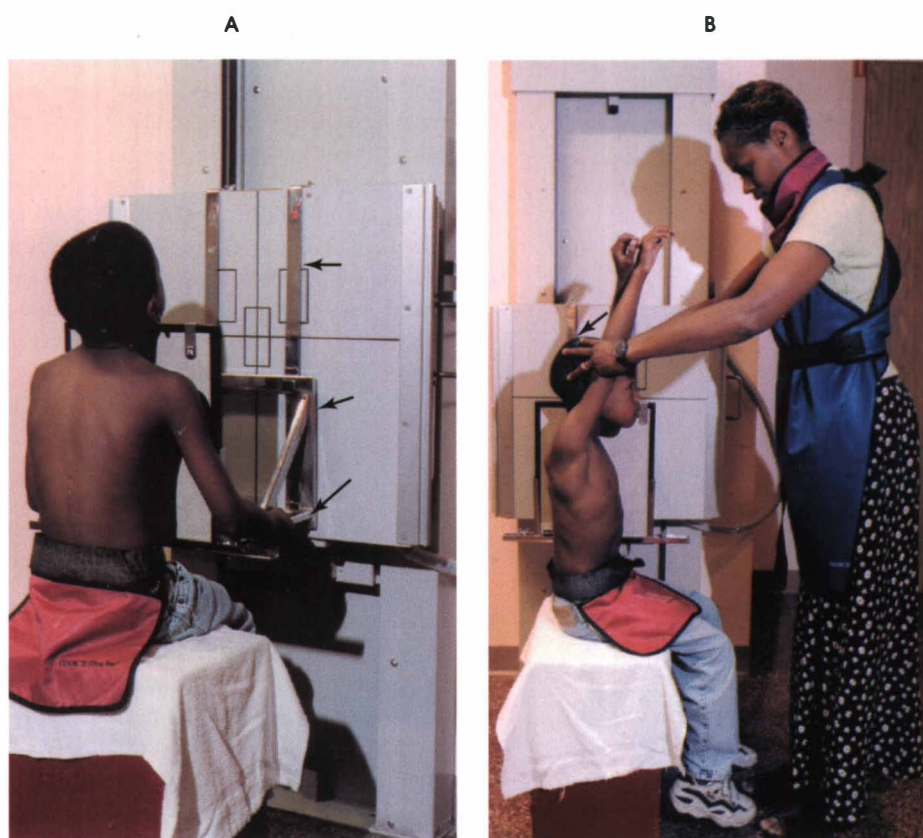
**Fig. 28-12** PA (**A**) and lateral (**B**) chest images of a 10-day-old patient with a pathologic cardiac condition. The Pigg-o-stat provides motionless, nonrotated radiographs of good inspiration. Note the presence of sternal wires (arrows), cardiac pacing wires (arrowheads), and a central venous line (dashed line). The nasogastric tube is seen well on the lateral image.



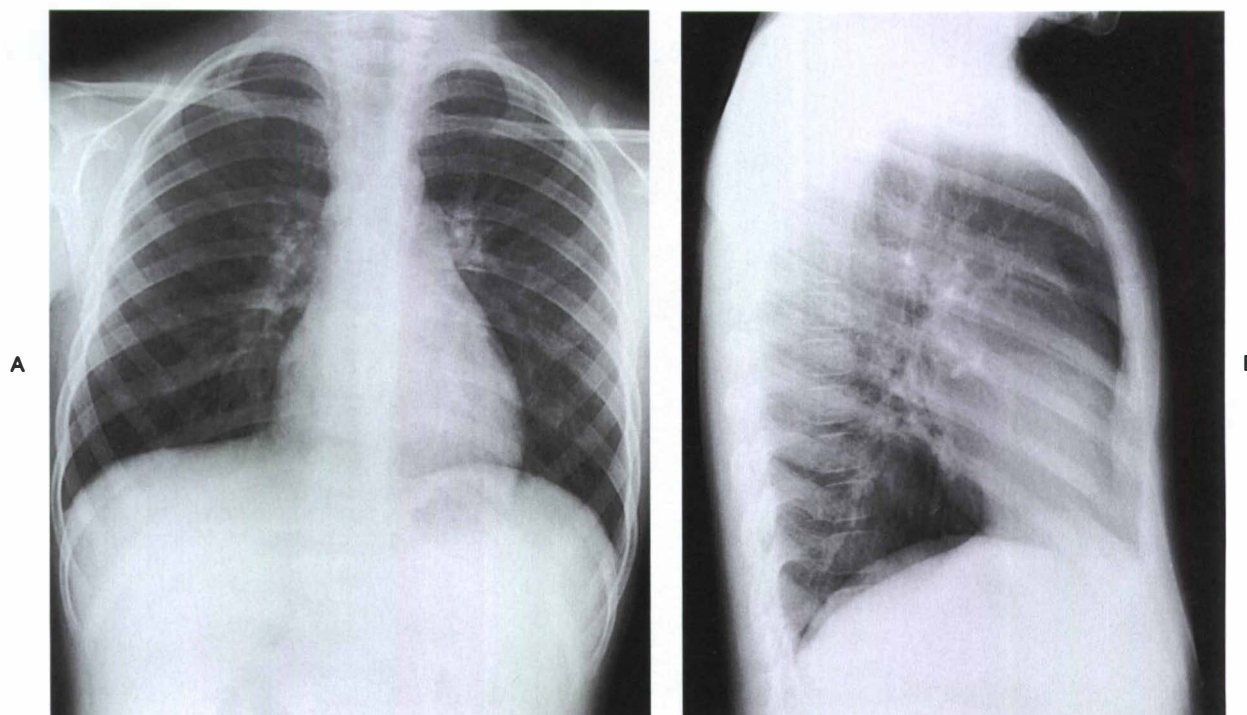
### Upright radiograph on the 3- to 18-year-old

Upright radiographs on 3- to 18-year-olds are easily obtained by observing the following steps:

- Help the child sit on a large wooden box, a wide-based trolley with brakes, or a stool, with the IR supported using a metal extension stand. Children of this age are very curious and have short attention spans. By having them sit, the radiographer can prevent them from wiggling from the waist down.
- For the PA radiograph, have the child hold on to the side supports of the extension stand, with the chin on top of or next to the IR. This prevents upper body movement.
- When positioning for the lateral radiograph, have the parent (if presence is permitted) assist by raising the child's arms above the head and holding the head between the arms (Fig. 28-13). PA and lateral chest images of a 6-year-old patient are shown in Fig. 28-14.



**Fig. 28-13** **A**, PA chest radiographs should be performed on the 3- to 18-year-old with the child sitting. **B**, The parent, if present, can assist with immobilization for the lateral image by holding the child's head between the child's arms. Metal extension stands (arrows on A and B) are commercially available from companies that market diagnostic imaging accessories.



**Fig. 28-14** PA (**A**) and lateral (**B**) radiographs of a seated 6-year-old boy. Large wooden boxes have the advantage of being sturdier than stools or trolleys, which often have wheels.



### Supine radiograph

Infants needing supine and cross-table lateral radiographs can be immobilized using Velcro straps around the knees and Velcro band across the legs Fig. 28-15. The patient is raised on a sponge with the arms held up and a cross-table lateral is performed. This is particularly useful for patients with chest tubes, delicately positioned gastrostomy tubes, or soft tissue swellings or protrusions that may be compromised by the sleeves of the Pigg-o-stat.

### Evaluating the image

As in adult chest radiography, the use of kVp is also desirable in pediatric chest work; however, this is relative. In adult work, high kVp generally ranges between 110 and 130 but for pediatric PA projections ranges between 80 and 90. Practically speaking, the use of a higher kVp is impossible because the corresponding mAs are too low to produce a diagnostic image. Relatively high kVp helps to provide images with long-scale contrast.

The criteria used to evaluate recorded detail include the resolution of peripheral lung markings. Evaluating any image for adequate density involves assessing the most and least dense areas of the demonstrated anatomy. In the PA chest image, the ideal technical factor is a selection that permits visualization of the intervertebral disk spaces through the heart (the most dense area) while still demonstrating the peripheral lung markings (the least dense area). Rotation should be assessed by evaluating the position of midline structures. Posterior and anterior midline structures (i.e., sternum, airway, and vertebral bodies) should be superimposed. The anatomic structures to be demonstrated include the airway (trachea) to the costophrenic angles. Similar to chest radiography in adults, the visualization of 9 to 10 posterior ribs is a reliable indicator of a radiograph taken with good inspiration (see Table 28-1).



**Fig. 28-15** The patient is raised on a sponge with arms held up by the head and the legs are immobilized using Velcro straps. The IR is in place for the horizontal lateral beam (cross-table lateral).

**TABLE 28-1**

Quick reference guide for radiograph assessment\*

	Density		Recorded detail	Contrast		Anatomy	Rotation check
	Most dense	Least dense		Long scale >3 shades	Short scale >3 shades		
PA Chest	Midline; inter-vertebral disk spaces, heart	Peripheral lung markings	Peripheral lung markings	Airway, heart, apices, bases, mediastinum, lung markings behind diaphragm and heart		Airway to bases	Airway position, S-C joints, lung field measurement, cardiac silhouette
PA Chest	Heart	Retrocadiac space	Peripheral lung markings	Airway, heart, apices, bases		Airway to bases, spinous processes to sternum	Superimposition of ribs, spinous processes on profile
Abdomen	Lumbar spine	Peripheral edges, soft tissue above crests of the ilia	Organ silhouettes	Diaphragm, liver, kidney, spine, gas shadows		Right and left hemidiaphragm, pubic symphysis, right and left skin edges	
Limbs	Bone	Soft tissue	Bony trabecular patterns		Bone, muscle, soft tissue	Joints above and below injury, all soft tissue	AP and lateral images must not resemble obliques
Hips	Hip joints	Iliac crests	Bony trabecular pattern		Bone, soft tissue	Iliac crests, lesser trochanter	Symmetric iliac crests
Lateral Lumbar Spine	L5-S1	Spinous processes	Bony trabecular pattern		Bone	T12 to coccyx, spinous processes to vertebral bodies	Alignment of posterior surfaces of vertebral bodies

\*Evaluating the radiograph to determine its diagnostic quality is a practiced skill. This chart, designed as a quick reference guide, outlines the five important technical criteria and the related anatomic indicators used in critiquing radiographs.



## HIP RADIOGRAPHY

The hip and pelvis are commonly examined radiographically in both the pediatric and adult population. However, the clinical rationale for ordering these examinations varies tremendously. The informed radiographer who understands these differences can be of great assistance. With a basic comprehension of some of the common pediatric pathologies and disease processes, the radiographer is better able to appreciate the skills required of the radiologist to make an accurate diagnosis.

### General principles

Both hips are examined, using the same projection for comparison. Hip examinations on children are most often ordered to assess for Legg-Calvé-Perthes disease (aseptic avascular necrosis of the femoral head of unknown etiology) and congenital dislocation of the hip and to diagnose nonspecific hip pain. Because these conditions require evaluation of the symmetry of the acetabula, joint spaces, and soft tissue, symmetric positioning is crucial.

Despite the importance of radiation protection, little written literature is available to guide radiographers on the placement of gonadal shields and when to use shielding. The radiographer should observe the following guidelines:

- *Always* use gonadal shielding on males. However, take care to prevent potential lesions of the pubic symphysis from being obscured.
- In females, use gonadal protection on all radiographs *except* the first AP projection of the *initial* examination of the hips and pelvis.
- After sacral abnormality or sacral involvement has been ruled out, use shielding on subsequent images in females.
- Before proceeding, check the girl's records or seek clarification from the parents regarding whether this is the child's first examination.
- Because the female reproductive organs are located in the mid-pelvis with their exact position varying, ensure that the shield covers the sacrum and part or all of the sacroiliac joints.

**NOTE:** Many children have been taught that no one should touch their "private parts." Radiographers need to be sensitive and use discretion when explaining and carrying out the procedure.

- *Never touch the pubic symphysis in a child*, regardless of whether you are positioning the patient or placing the gonadal shield.
- Remember that the superior border of the pubic symphysis is always at the level of the greater trochanters, and use the trochanters as a guide for both positioning and shield placement.
- In males, keep the gonadal shield from touching the scrotum by laying a 15-degree sponge or a cloth over the top of the femora. The top of the shield can be placed level with the trochanters and the bottom half of the shield can rest on top of the sponge or cloth (Fig. 28-16).
- In females, place the top, widest part of the shield in the midline, level with the anterior superior iliac spine (ASIS).

### Initial images

The preliminary examination of the hips and pelvis on children includes a well-collimated AP projection and a projection in what is commonly referred to as the "frog leg" position. This position is more correctly described as a coronal image of the pelvis with the thighs in abduction and external rotation, or the frog (Lauenstein) lateral projection (see Chapter 7).

### Preparation and communication

All images of the abdomen and pelvic girdle should be performed with the diaper completely removed. This is *essential* for radiography of the hips and pelvis. Diapers, especially wet diapers, produce significant artifacts on radiographs, often rendering them undiagnostic. The radiographer or imaging department staff member should place all necessary sponges, gonadal shielding, Velcro strips, and Velcro restraining bands on the table before beginning the examination.

Children are usually familiar with Kermit the Frog. Explaining that the child will pretend to be Kermit serves nicely.



**Fig. 28-16** The male gonad shield should cover the scrotum without obscuring the pubic symphysis. The greater trochanters indicate the upper border of the pubic symphysis; the top of the shield should be placed approximately  $\frac{1}{2}$  inch below this level. The gonadal shield rests on a 15-degree sponge, which prevents the radiographer's hands from coming close to or touching the scrotal area.



### Positioning and immobilization

As described previously, *symmetric positioning* is of great importance. However, as in many examinations, the hip positions that are the most uncomfortable for the patient are often the most crucial. When a child suffers from hip pain or dislocation, symmetric positioning is difficult to achieve because the patient often tries to compensate for the discomfort by rotating the pelvis. The radiographer should observe the following steps when positioning the patient:

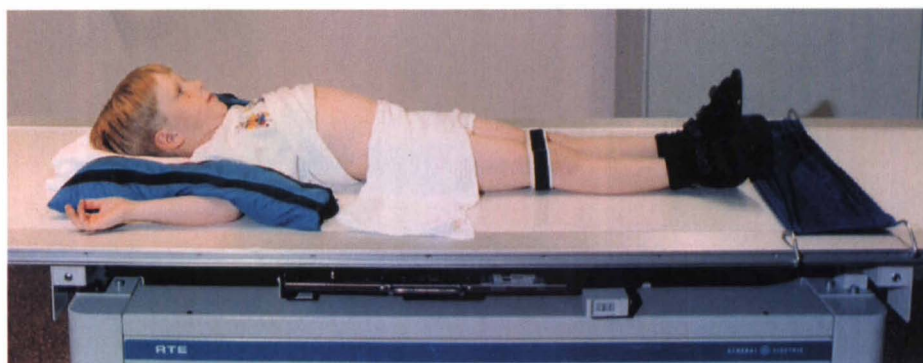
- As with hip examinations on any patient, check that the ASISs are equidistant from the table.
- After carefully observing and communicating with the patient to discover the location of pain, the radiographer can use sponges to compensate for rotation. Sponges should routinely be used to support the thighs in the frog leg position. This can help prevent motion artifacts.
- Do not accept poorly positioned images. Expend considerable effort in attempting to achieve optimal positioning. This effort may include giving instructions, or repeating instructions to the novice pediatric radiographer.

Because *immobilization techniques* should vary according to the aggressiveness of the patient, the radiographer can follow these additional guidelines:

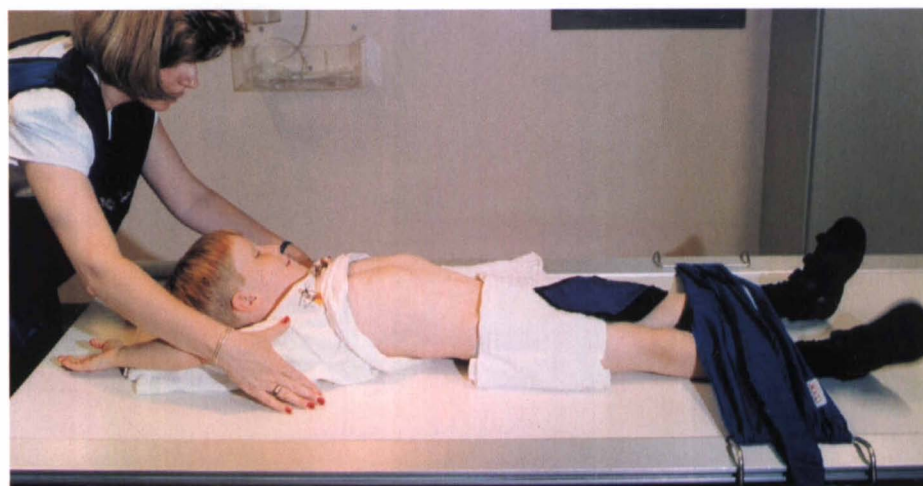
- Make every effort to use explanation and reassurance as part of the immobilization method. The child may require only a Velcro band placed across the legs as a safety precaution (see Fig. 28-16).
- For the active (or potentially active) child, wrap a Velcro strip around the knees and place large sandbags over the arms (Fig. 28-17). The Velcro strip around the knees keeps the child from wiggling one leg out from under the Velcro band. After getting one leg out, the child may get the other out and possibly roll off the table.
- If the child has enough strength to free the arms from the sandbags, ask a parent to stand on the opposite side of the table from the radiographer and hold the child's humeri. The parent's thumbs should be placed directly over the child's shoulders (Fig. 28-18). This method of immobilization is used extensively. It works well for supine abdominal images, intravenous urograms (IVUs), intravenous pyelograms (IVPs), overhead GI procedures, and spinal radiography.

### Evaluating the images

Rotation or symmetry can be evaluated by ensuring that midline structures are, in fact, in the midline and that the ilia appear symmetric. Depending on the degree of skeletal maturation, visualization of the trochanters can indicate the position of the legs when the radiograph was taken. Symmetry in the skin folds is also an important evaluation criterion for the diagnostician. The anatomy to be demonstrated includes the crests of the ilia to the upper quarter of the femora. The density should be such that the bony trabecular pattern is visible in the hip joints, the thickest and most dense area within the region. The visualization of the bony trabecular pattern is used as an indicator that sufficient recorded detail has been demonstrated. This, of course, should not be at the expense of demonstrating the soft tissues—the muscles and skin folds (see Table 28-1).



**Fig. 28-17** Immobilization of the active child: sandbags over the arms, Velcro strips around the knees, and a Velcro band beside the patient's feet to be secured over the legs, as in Fig. 28-15.



**Fig. 28-18** If the child is strong enough or aggressive enough to remove the sandbags, the parent can hold the child's humeri by placing the thumbs directly over the child's shoulders.

## SKULL RADIOGRAPHY

Along with radiography of the limbs, skull radiography presents some of the greatest challenges to the radiographer. Indeed, cranial radiography is usually one of the last areas students become comfortable with during their clinical education.

The reasons are twofold: (1) anatomically speaking, the skull is complex, and (2) the frequency of skull examinations has steadily decreased with the increased availability of CT (see Chapter 33) and MRI (see Chapter 36). Pediatric patients such as the 3-year-old in Fig. 28-19 are an even greater challenge.

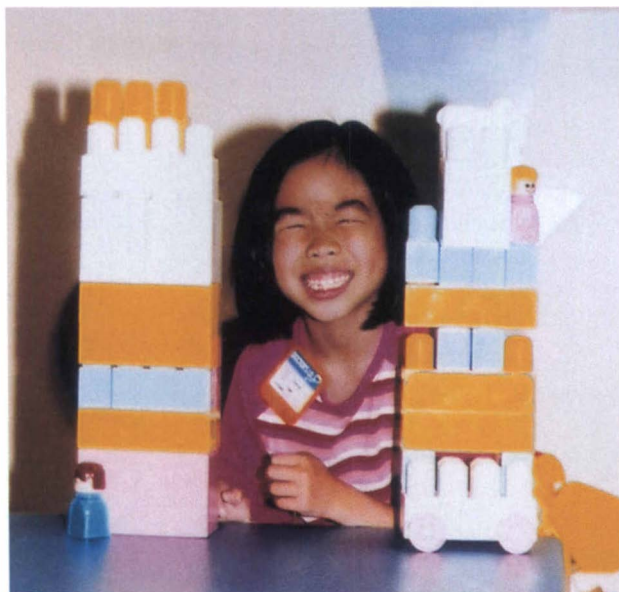


Fig. 28-19 This little girl's face indicates a challenge for skull radiography.

The problems associated with cranial radiography in children can be lessened by *preparing the room* before the patient and parent enter (Fig. 28-20) and avoiding *two common pitfalls*: (1) ineffective immobilization and (2) forgetting (or not taking the time) to check the first radiograph of a skull series. The first image should be treated as a *scout radiograph*, an image that permits assessment of the exposure factors and allows the radiographer to tailor the remaining images to suit the peculiarities of the individual patient. The clinical rationale for performing skull radiography differs tremendously between pediatric and adult patients. Children who arrive in the imaging department for skull examinations may have congenital abnormalities that significantly alter the bone density. Their age and consequent degree of skeletal maturation also affect bone density. These factors need to be considered as the technical factors are selected. Therefore the viewing of the initial image is very important.

### Immobilization

All patients 3 years old and younger should be immobilized using the "bunny" technique illustrated in Fig. 28-21. (An exception to this rule is the sleeping child.) A well-wrapped child remains that way through five to seven images. Mastering this technique is clearly one of the secrets to successful immobilization. A few words of explanation to the parent regarding the need to wrap the child, along with some instructions for ways the parent can help, are also very beneficial. Experience has shown that although children initially do not like being wrapped up using this technique, after their initial frustration and perhaps the use of a pacifier, they often settle down and occasionally fall asleep. If beneficial, the pacifier can be left in the patient's mouth for every image with the exception of the reverse AP projection. The parent must be cautioned not to unwrap the child until all radiographs have been checked for diagnostic quality.

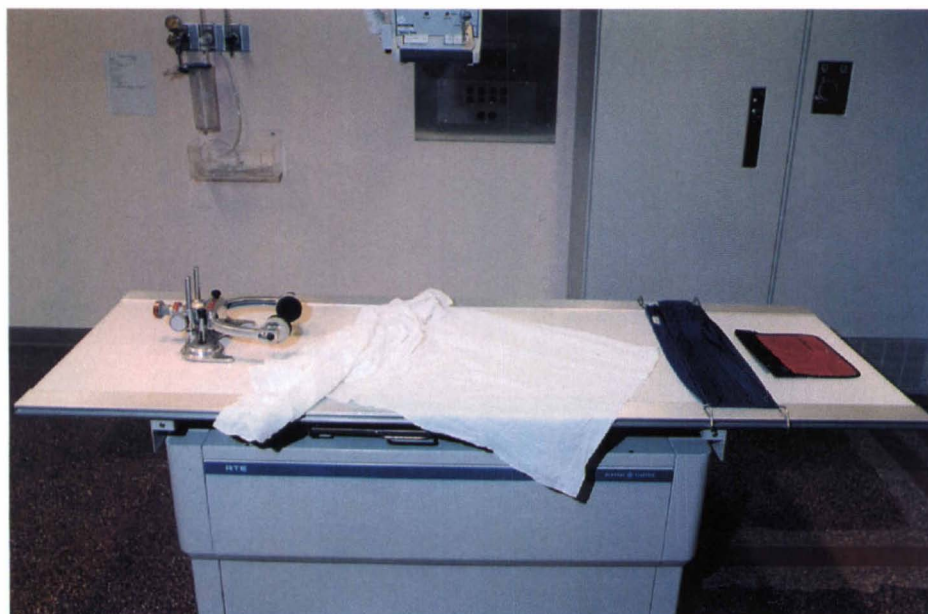
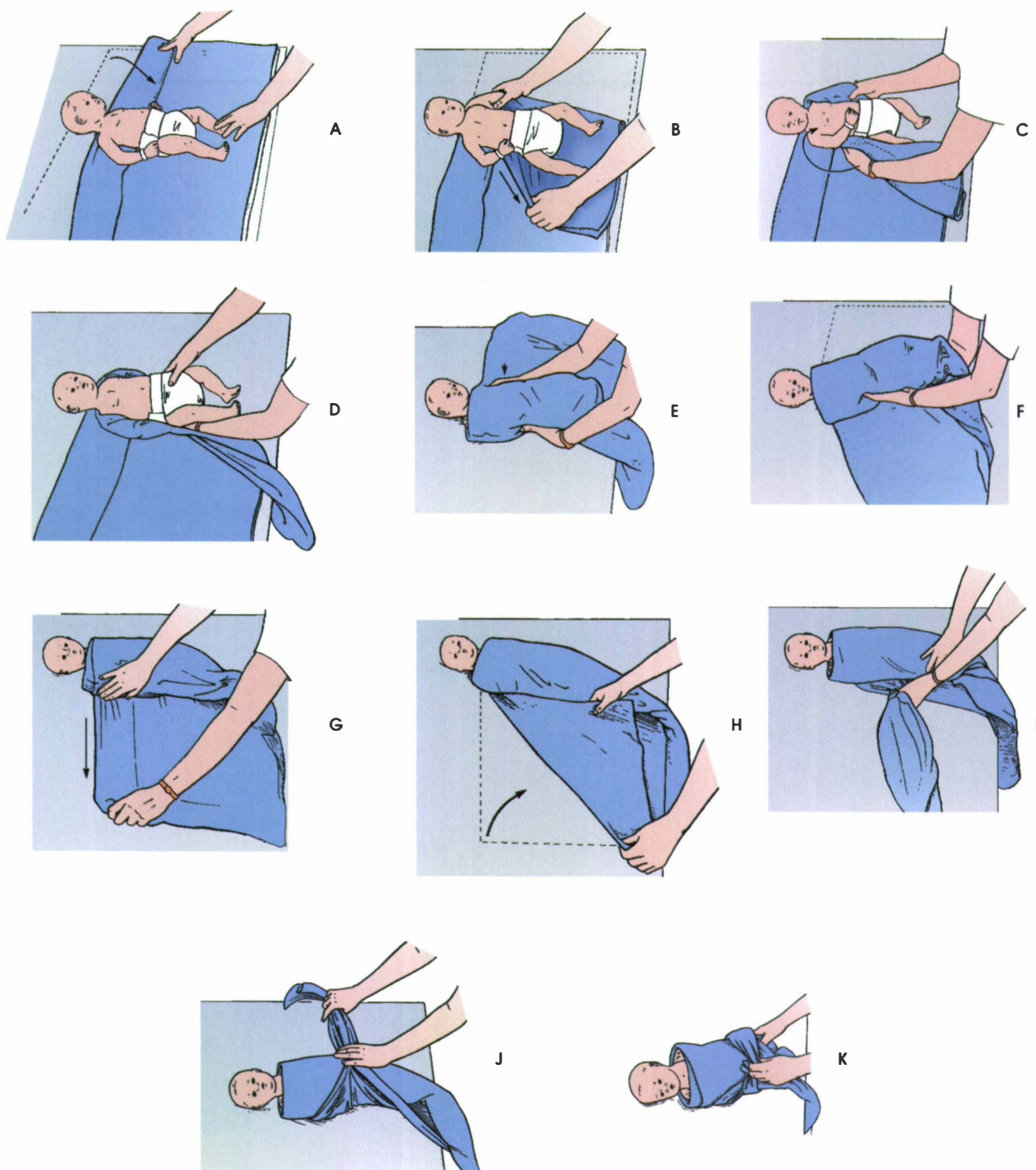


Fig. 28-20 The well-prepared radiographer can make a potentially difficult skull examination go smoothly. Note the gonadal shield, Velcro band, and head clamps in place. A standard hospital sheet has been unfolded and placed on the table to prepare for immobilization using the "bunny" technique.

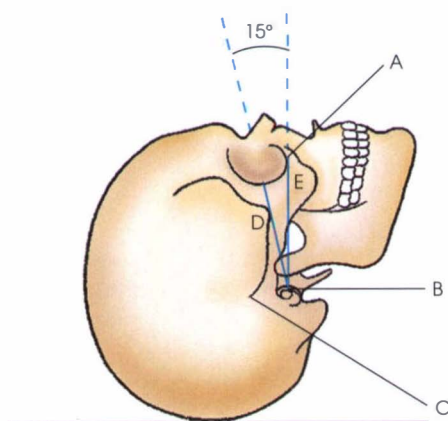




**Fig. 28-21** The "bunny" method used to immobilize the patient for cranial radiography. **A** to **D** focus on immobilization of the shoulders, **E** to **G** concentrate on the humeri, and **H** to **K** illustrate the way the sheet is folded and wrapped to immobilize the legs. **A**, Begin with a standard hospital sheet folded in half lengthwise. Make a 6-inch fold at the top, and lay the child down about 2 feet from the end of the sheet. **B**, Wrap the end of the sheet over the left shoulder, and pass the sheet under the child. **C**, This step makes use of the 6-inch fold. Reach under, undo the fold, and wrap it over the right shoulder. (Steps **B** and **C** are crucial to the success of this immobilization technique because they prevent the child from wiggling the shoulders free.) **D**, After wrapping the right shoulder, pass the end of the sheet under the child. Pull it through to keep right arm snug against the body. **E**, Begin wrapping, keeping the sheet snug over the upper body to immobilize the humeri. **F**, Lift the lower body and pass the sheet underneath, keeping the child's head on the table. Repeat steps **E** and **F** if material permits. **G**, Make sure the material is evenly wrapped around the upper body. (Extra rolls around the shoulder and neck area produce artifacts on 30-degree fronto-occipital and submentovertical radiographs.) **H**, Make a diagonal fold with the remaining material (approximately 2 feet). **I**, Roll the material together. **J**, Snugly wrap this over the child's femora. (The tendency to misjudge the location of femora and thus wrap too snugly around the lower legs should be avoided.) **K**, Tuck the end of the rolled material in front. (If not enough material remains to tuck in, use a Velcro strip or tape to secure it.)

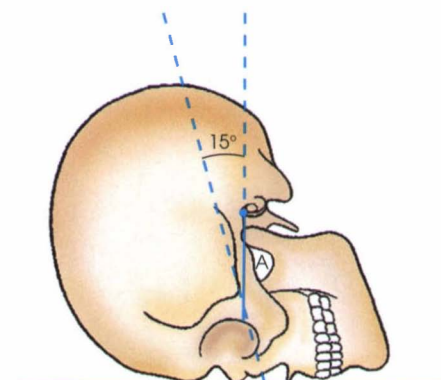
(From The Michener Institute for Applied Health Sciences, Toronto.)



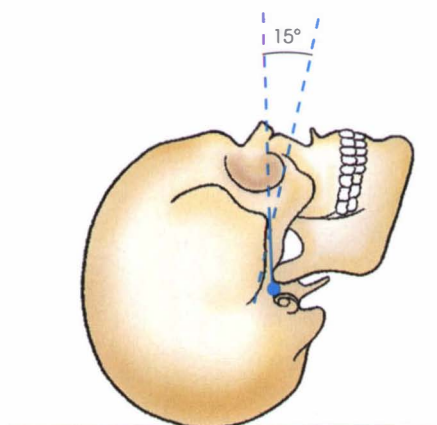


**Fig. 28-22** Established tube angles and positions modified to suit the pediatric patient: **A**, infraorbital margin; **B**, EAM; **C**, petrous ridge; **D**, OML; **E**, IOML. Note that in the young child the OML and IOML are 15 degrees apart (in contrast to older children and adults, where the difference can be 15 to 20 degrees). For simplicity, these diagrams adopt a convention of 15 degrees.

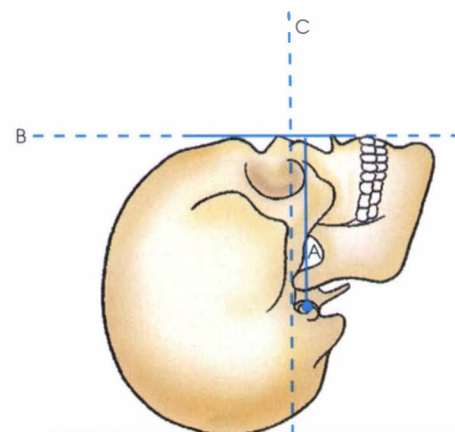
(Courtesy K. Edgell, Cook Inc., Toronto.)



**Fig. 28-23** PA projection with OML perpendicular to the table. In the older child, teenager, and adult, a 15- to 20-degree caudal angulation results in the petrous ridges being projected in the lower third of the orbits. In infants and young children, a 10- to 15-degree caudal angulation achieves the same result.



**Fig. 28-24** AP projection with the OML perpendicular to the table. This projection requires a 15-degree cephalad angulation to project the petrous ridges in the lower third of the orbits.



**Fig. 28-25** The IOML (**A**) is positioned perpendicular to the table with the patient in a comfortable position—one the head and neck naturally assume as the patient lies down. (A comfortable patient is more likely to remain still.) With the patient positioned this way, the tube does not have to be angled cephalad to project the petrous ridges in the lower third of the orbits (represented by dotted line, **C**). With the necessary head clamps positioned, the IOML remains perpendicular to the film. With the IOML perpendicular to the IR, the forehead and chin are parallel to the IR (dotted line, **B**).

### Positioning

The skull grows rapidly in the first 2½ years of life, approaching the 75th percentile of adult size by that age. The radiographer must understand the way this growth and the rate at which the cranium grows relative to the facial bones alter the position of the various radiographic landmarks and angles.

*Practical tip:* The established cranial angulations (see Chapter 20) can be adapted to suit young children by decreasing the angulation of the central ray by 5 degrees. The line diagrams in Figs. 28-22 to 28-25 put this in perspective. The PA projection is used as the basis for these diagrams because this image projects the petrous ridges in the lower one third of the orbits, which is a common baseline radiograph for many departments.

Head clamps should be used on all children, even sleeping children. Although motion may not be a factor, the sleeping child's head needs some support to maintain the required positions. (The lateral image may be an exception if the child has fallen asleep on the back with the head turned to the side.) Many radiographers believe that the use of head clamps further agitates some children.

As with any form of immobilization, acceptance of the method depends greatly on the way it is introduced to the patient and parent. If the room is prepared before the patient enters, the head clamps should already be in position. Attention need not be drawn to the head clamps until they are about to be used, and they can then be referred to as " earmuffs" (Fig. 28-26). This avoids the unnecessary anxiety that may otherwise be experienced. The degree to which the clamps are tightened depends on the situation. Some children need them only as a reminder to keep still, whereas others need to have them adjusted more tightly. Although various kinds of head clamps are available, clamps with a suction cup base are particularly effective and versatile. (The problem some users experience with the suction cups not sticking to the table is often eliminated by lightly wetting the rubber cups.)

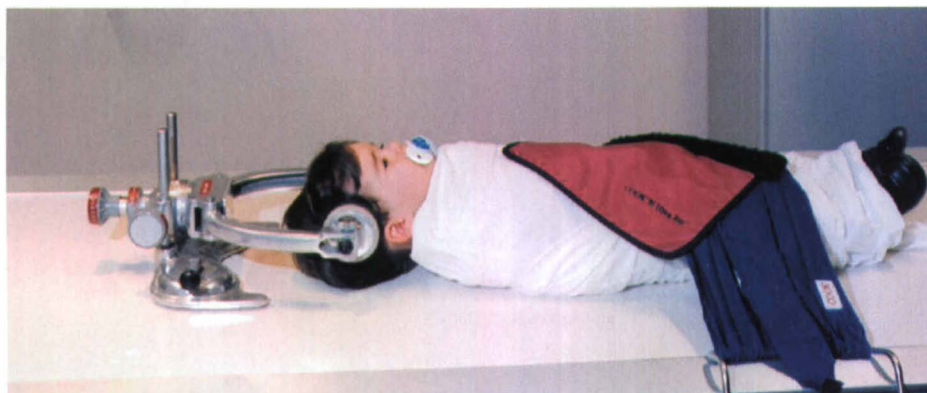


Fig. 28-26 AP projection with head clamps in place.

TABLE 28-2

Protocols for neurologic and trauma/injury radiographic routines\*

Neurologic routine	Trauma/injury routine
PA or reverse PA projection (Fig. 28-26)	PA or reverse PA projection (Fig. 28-26)
30-degree frontooccipital projection	30-degree frontooccipital projection
Lateral with vertical beam (Fig. 28-27)	Lateral with horizontal beam (28-28)
Submentovertical projection (Fig. 28-29)	

\*The important differences between neurologic and trauma/injury routines are the inclusion of a submentovertical projection in the neurologic routine and the need for the lateral image to be performed using a horizontal beam in the trauma/injury routine. This lateral image with a horizontal beam is often referred to as a *cross-table lateral* and is performed to assess possible air/fluid levels that may occur as a result of the injury.

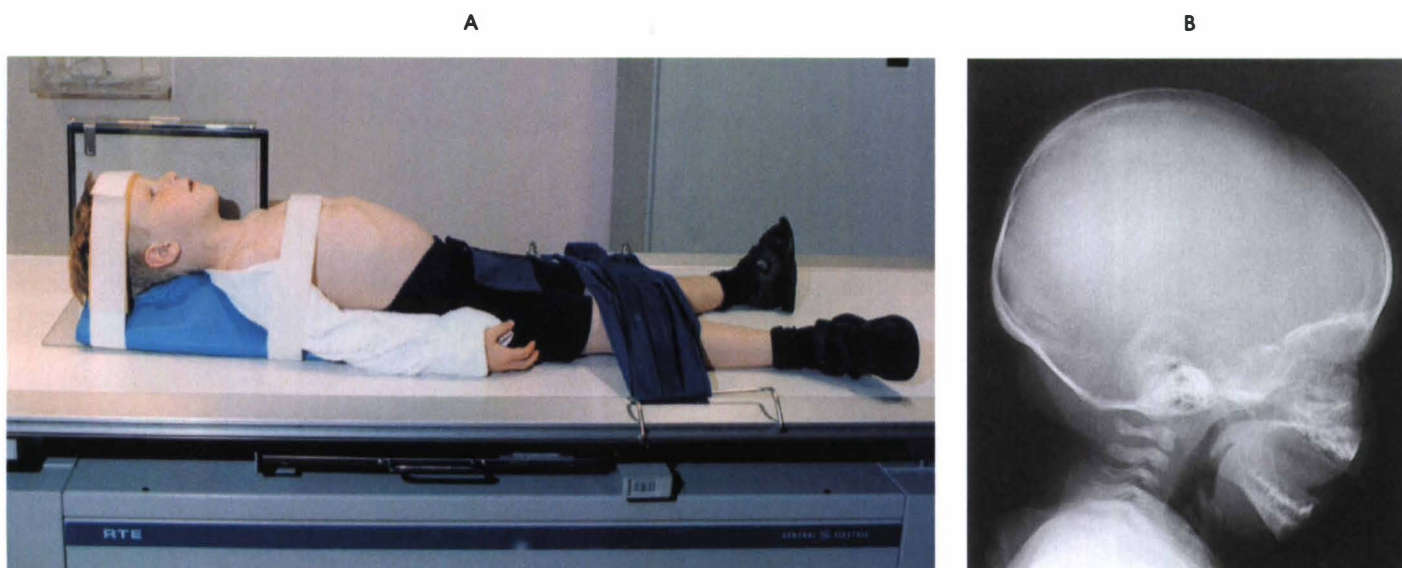


**Fig. 28-27** When other methods prove unsuccessful, effective immobilization for a lateral skull radiograph with a vertical beam can be achieved with the use of a second Velcro band—and some additional explanation to the parent. Some radiographers question the technique because it covers the child's eyes. Turning the child's head and placing the Velcro band should be the last step (apart from a quick collimation check) before the exposure is made. Anxiousness can be alleviated if the parent bends down facing the child and talks to the child for the few seconds the radiographer needs to make the exposure.

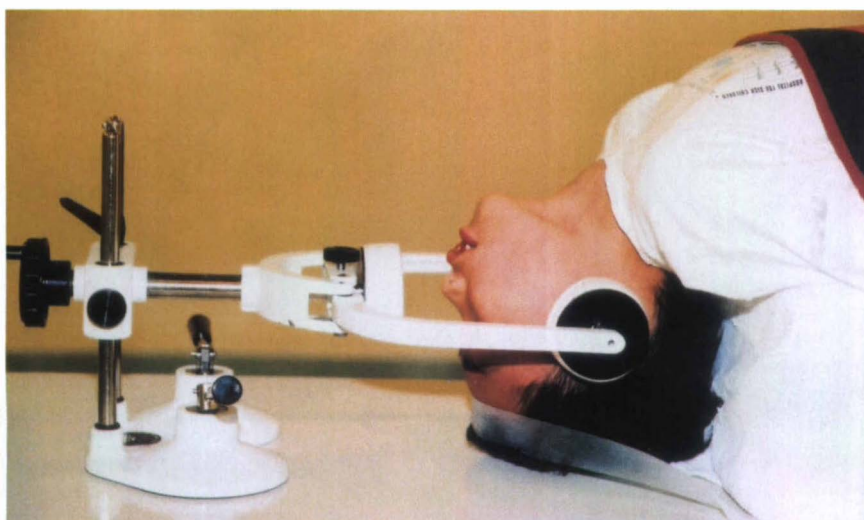


### Routines and protocols

Physicians order skull radiographs to assess neurologic problems and evaluate the extent of trauma or injury. For these reasons, many departments develop two routines: neurologic and trauma (Table 28-2; Figs. 28-27 to 28-29).



**Fig. 28-28** **A**, Effective immobilization for lateral skull images with a horizontal beam can be achieved using the infant head and neck immobilizer. **B**, The resultant image reveals a well-positioned, nonrotated lateral skull image, including the upper cervical spine.



**Fig. 28-29** Positioning for a submentovertical projection. Note the use of tape over the forehead to help maintain extension. (The tape is flipped over so that the nonsticky surface is in contact with the child's forehead.)

## LIMB RADIOGRAPHY

Limb radiography, which accounts for a high percentage of pediatric general radiographic procedures in most clinics and hospitals, requires some explanation. The child's age and demeanor determine the method of immobilization to be employed. The immobilization methods are described here according to age group. In planning the approach, the radiographer should consider the chronologic age and psychologic outlook of the patient. For example, a very active 3-year-old may be better managed using the approach for newborns to 2-year-olds.

### Immobilization

#### Newborn to 2-year-old

Limb radiography on the newborn to 2-year-old is probably the most challenging; however, it is made easier when the patient is wrapped in a towel. (A pillow case will suffice if a towel is not available.) This wrapping technique, a modification of the "bunny" method described previously, keeps the baby warm and allows the radiographer (and the parent, if assisting) to concentrate on immobilizing the injured arm. Fig. 28-30 demonstrates the method by which a piece of Plexiglas and "bookends" can be used to immobilize the hand.

*Lower limbs* on patients in this age group pose the greatest challenge in all pediatric limb work. In general, both arms should be wrapped in the towel and a Velcro band should be placed across the abdomen. A large sandbag is then placed over the unaffected leg (Fig. 28-31).

#### Preschoolers

The upper limbs of preschoolers are best examined radiographically with the child sitting on the parent's lap as shown in Fig. 28-32. If the parent is unable to participate, these children can be immobilized as described previously.

With parental participation, radiography of the lower limbs can be accomplished with the child sitting or lying on the table. Preventing the patient from falling from the table is always a primary concern with preschoolers. The parent must be instructed to remain by the child's side if the child is seated on the table. If the examination is performed with the child lying on the table, a Velcro band should be placed over the child.

#### School-age children

School-age children can generally be managed in the same way adult patients are for both upper and lower limb examinations.



**Fig. 28-30** With a simple modification of the "bunny" technique using a towel (or pillowcase), the child can be immobilized for upper limb radiography. Plexiglas (*dashed lines*) and "book-ends" (*B*) can be used to immobilize the hands of children 2 years old and younger. Note that after the child is wrapped, a Velcro band is used for safety and a small apron is placed diagonally over the body to protect the sternum and gonads. The IR is placed on a lead mat, which prevents the image receptor from sliding on the table.





**Fig. 28-31** The challenges of immobilizing lower limbs are greater than those of immobilizing upper limbs. After wrapping both of the patient's arms in a towel and placing a Velcro band over the abdomen, the radiographer can place a large sandbag over the unaffected leg. With careful collimation and proper instruction the parent can hold the limb as demonstrated. (The parent's hands shown without lead gloves and not draped in lead for illustration purposes only.)



**Fig. 28-32** Preschoolers are best managed sitting on a parent's lap. A lead mat is used to keep the IR from sliding. Note use of Plexiglas to immobilize fingers.





Fig. 28-33 The teddy bear on this full-length apron makes it appropriate for young children.

### Radiation protection

The upper body should be protected in all examinations of the upper limbs, because of the close proximity of the thymus, sternum, and breast tissue to the scatter of the primary beam. Child-sized lead aprons with cartoon characters are both popular and practical (Fig. 28-33).

### Management of fractures

As with adult patients who arrive in the imaging department with obvious fractures, the child with an obvious fracture *must* have the limb properly splinted by qualified personnel before the radiographer commences the examination. The splint protects both the patient and the radiographer, because the radiographer could cause further injury by manipulating an unsplinted limb.

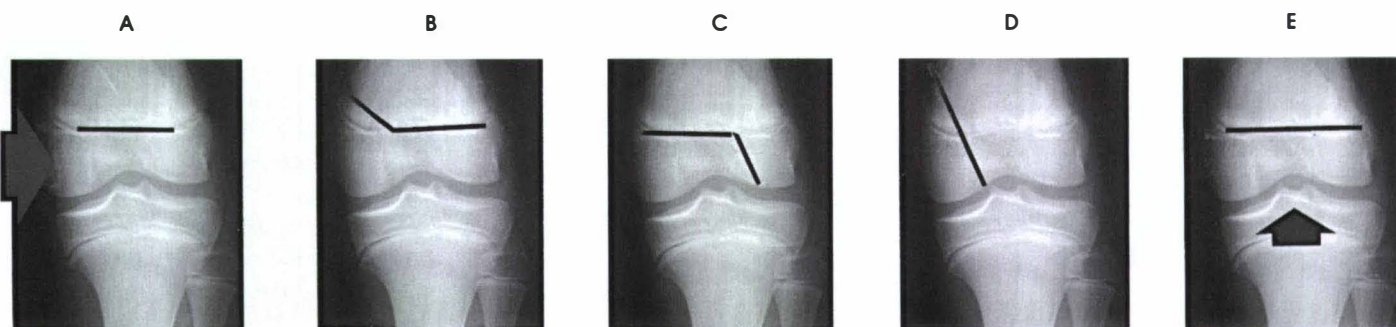
Patients with fractures often arrive in the imaging department on a stretcher. The radiographer skilled at adapting routines can often obtain the necessary radiographs without moving the patient onto the table.

Ways to manage patients with Osteogenesis Imperfecta were discussed in a previous section of this chapter (see Patient Care sections).

### Evaluating the image

One of the most striking differences between adult and pediatric patients is the radiographic appearance of the limb. Radiographers develop an appreciation for these differences, which are caused by the presence of epiphyseal lines, as they gain experience in evaluating pediatric images. In departments in which the patient mix includes children and adults, preliminary limb work may require the *contralateral* side to be examined for comparison purposes. To the uneducated eye, a normally developing epiphysis may mimic a fracture. For this reason and because fractures can occur through the epiphyseal plate, physicians must learn to recognize epiphyseal lines and their appearance at various stages of ossification. Fractures that occur through the epiphysis are called *growth plate fractures*. Fig. 28-34 illustrates five types of epiphyseal fractures, referred to as *Salter-Harris type fractures*, the most widely used form of classification.

Because the growth plates are composed of cartilaginous tissue, the *density* of the radiographic image must be such that soft tissue is demonstrated in addition to bone (see Table 28-1). As previously described for radiography of the hip, the visualization of the bony trabecular pattern is used as an indicator that sufficient *recorded detail* has been demonstrated. Because of the smallness of pediatric limbs, an imaging system that provides better resolving power is usually required. As a general rule the speed of the imaging system used for limb radiography should be half that used for spines and abdomens.



**Fig. 28-34** Salter-Harris fractures. The black lines represent the fracture lines. **A**, A type 1 fracture occurs directly through the growth plate. **B**, A type 2 fracture extends through the growth plate and into the metaphyses. **C**, A type 3 fracture line extends through the growth plate and into the epiphyses. **D**, A type 4 fracture line extends through the metaphyses, across or sometimes along the growth plate, and through the epiphyses. **E**, A type 5 fracture involves a crushing of all or part of the growth plate. Fractures that occur through the epiphyses are significant injuries because they can affect growth if not recognized and treated properly. Proper radiographic technique is required for the demonstration of both soft tissue and bone. This is especially important with type 1 fractures, in which the growth plate is separated as a result of a lateral blow, and type 5 fractures, in which the growth plate has sustained a compression injury. Types 1 and 5 fractures do not occur through the bone.





**Fig. 28-35** The Pigg-o-stat, modified with the seat raised to suit upright abdominal radiography. The sleeves and seat are cleaned, and the seat is covered with a cloth diaper or thick tissue before the patient is positioned.

## ABDOMINAL RADIOGRAPHY

Abdominal radiography for children is requested for different reasons than it is for adults. Consequently the initial procedure or protocol differs significantly. In addition to the supine and upright images, the assessment for acute abdomen conditions or the abdominal series in adult radiography usually includes radiographs obtained in the left lateral decubitus position. Often the series is not considered complete without a PA projection of the chest. To keep radiation exposure to a minimum, the pediatric abdominal series need only include two images: the supine abdomen and an image to demonstrate air-fluid levels. The upright image is preferred over the lateral decubitus in patients under 2 or 3 years of age because, from an immobilization and patient comfort perspective, it is much easier to perform. The upright image can be obtained with a slight modification of the Pigg-o-stat whereas the lateral decubitus position requires significant modification of the Pigg-o-stat.

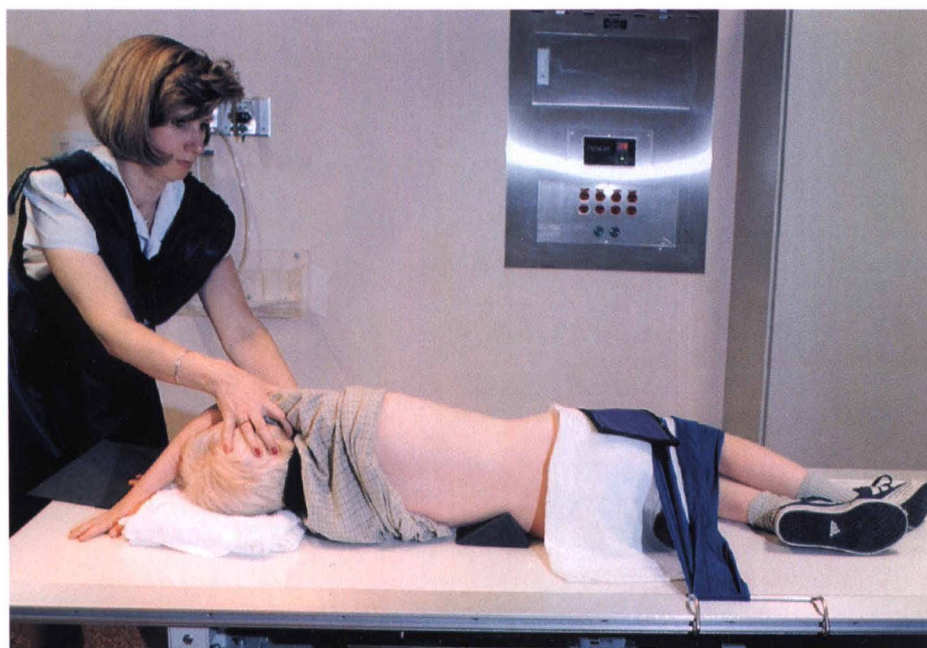
## Positioning and immobilization

Young children can be immobilized for supine abdomen imaging with the same methods described for radiography of the hips and pelvis (see Fig. 28-17), methods that provide basic immobilization of a patient for supine table radiography. The radiographer should observe the following guidelines for upright abdominal imaging:

- Effectively immobilize newborns and children as old as 3 years for the upright image using the Pigg-o-stat.
- Raise the seat of the Pigg-o-stat to avoid projecting artifacts from the bases of the sleeves over the lower abdomen (Fig. 28-35).
- For the best results in the older child, have the child sit on a large box, trolley, or stool and spread the legs apart to prevent superimposition of the upper femora over the pelvis.

*Lateral images* of the abdomen are occasionally required in children, generally to localize something in the AP plane. Immobilization for lateral images is quite challenging; this difficulty, along with the fact that patient immobilization is the same as for lateral spine images, makes it worthy of mention here. Properly instructed, the parent can be helpful with this radiograph. The radiographer should observe the following steps:

- Remember that the *parent can do only one job*.
- Ask the parent to stand on the opposite side of the table and hold the child's head and arms.
- Immobilize the rest of the child's body using available immobilization tools. These tools include large 45-degree sponges, sandbags (large and small), a "bookend," and a Velcro band.
- Accomplish immobilization by rolling the child on the side and placing a small sponge or sandbag between the knees.
- Snugly wrap the Velcro band over the hips; to prevent backward arching, place the "bookend" against the child's back with the 45-degree sponge and sandbag positioned anteriorly (Fig. 28-36).



**Fig. 28-36** The immobilization used for lateral abdominal imaging is also very effective for lateral thoracic and lumbosacral spine images. A 45-degree sponge and sandbag are used anteriorly.



**Practical tip:** It is common for pediatric clinicians to request “two projections of the abdomen.” The accompanying clinical information should support this request; if it does not, the radiographer should seek *clarification before proceeding*. Depending on the clinical reason for the radiographs, the two images may need to be supine and lateral. Abdominal images requested for infants in the NICU illustrate this point well. The neonatal patient with *necrotizing enterocolitis* requires supine and left lateral decubitus radiographs to rule out air-fluid levels indicative of bowel obstruction. However, the patient with an umbilical catheter needs supine and lateral images to verify the location and position of the catheter.

## GASTROINTESTINAL AND GENITOURINARY PROCEDURES

In the interest of limiting radiation exposure to the GI and genitourinary systems, examinations are tailored to the individual patient. After a brief introduction, the radiographer should explain the procedure and check that the patient has undergone proper bowel preparation. The radiographer can then proceed with preparation (e.g., enema tip insertion) and immobilization of the patient.

Most procedures are performed by the radiologist. Exceptions include IVUs and in some hospitals voiding cystourethrograms (VCUGs). Notwithstanding, the radiographer has an integral role in the success of all examinations. Optimal hard-copy images require a thorough understanding of the equipment, its capabilities, and its limitations. Good patient care and organizational skills can also make the examination proceed more smoothly.

## Immobilization for gastrointestinal procedures

As with other immobilization techniques, various beliefs exist regarding immobilization methods for the fluoroscopic portion of GI procedures; two methods are described. (The child may be immobilized for the “overhead” images as per the method outlined for the supine abdomen examination.)

### Modified “bunny” method

The child’s torso and legs are wrapped in a small blanket or towel and secured with a Velcro strip or tape. The arms are left free, raised above the head, and held by the parent (if present) (Fig. 28-37). The radiologist can then operate the carriage with one hand, holding the child’s legs with the other to rotate the patient, thus obtaining the necessary coating of barium. This technique, thought by many to be more comfortable for the child, is often preferred by radiologists because small blankets are more readily available than the octagonal infant immobilization device. Success with this technique depends on someone (often a parent) assisting.

Conventional fluoroscopic suites, as contrasted to remote suites, are often preferred for GI examinations on children under 5 years old. Infants and preschoolers often require hands-on assistance to achieve desired positions and ensure their safety. In addition, the scattered dose is easier to minimize in conventional suites (see Radiation protection for GI procedures in the next section).



**Fig. 28-37** Another modification of the “bunny” technique. The arms are left free and are raised above the head to prevent superimposition over the esophagus. In this example, tape is used to secure the blanket; however, Velcro strips are easier to use if a parent is not available to assist.

### Octagonal infant immobilization method

The octagonal infant immobilization method, although effective, is less comfortable and appears more traumatic. However, with some creativity on the part of staff members, much of the child's fear can be averted by playing the "rocket ship game." The 3-year-old in Fig. 28-38 was told he would be dressed in a space suit (the hospital gown) and would go for a ride in the rocket ship.

By virtue of its construction, the octagonal immobilizer provides immobilization of the child in a variety of positions. As with the Pigg-o-stat, initial positioning of the child is a two-person process. The additional person does not have to be another radiographer; a well-instructed parent can assist. Because this technique immobilizes the head and arms, it is the method of choice when a parent is unable to provide assistance.



Fig. 28-38 The octagonal immobilizer (or for this child a "rocket ship") permits the child to be immobilized in a variety of positions.

### Radiation protection for gastrointestinal procedures

It is good practice to cover most of the tabletop of conventional fluoroscopic units with large mats of lead rubber (the equivalent of 0.5 mm of lead is recommended) (see Fig. 28-38). Effective protection for operators and patients can be achieved by positioning the mats so that only the areas being examined are exposed.

### Voiding cystourethrogram for genitourinary procedures

A primary purpose of the VCUG is to assess vesicoureteral reflux (reflux from the bladder to the ureters). In addition, VCUG in males can identify and evaluate urethral strictures. Radiation protection for the fluoroscopic portion should be the same as outlined above for GI examinations. The VCUG assesses bladder function and demonstrates ureteral and urethral anatomy.

### Method

The patient is catheterized, a procedure that often requires two people—one to perform the catheterization and one to immobilize the legs in a frog leg position. The catheter is connected via tubing to a 500-ml bottle of contrast medium hung about 3 feet above the table. Under fluoroscopic guidance, contrast medium is dripped into the bladder until the bladder is full. Images are then taken while the patient is voiding to demonstrate reflux. This is often easier said than done! Preschoolers who have just been "toilet trained" and older children are often embarrassed. Techniques such as running tap water or pouring warm water over the genital area often encourage children to void.

### Positioning

The female patient remains in the supine position, but the male patient must be placed in an oblique position during voiding to prevent the urethra from being superimposed over the pubic symphysis. After placing the male in an oblique position, the radiographer should take care to ensure the urethra is not superimposed over the femur.

### Intravenous urogram for genitourinary procedures

Most pathologic conditions identified on an IVU or IVP can also be diagnosed with ultrasonography, a noninvasive, radiation-free examination. These advantages, combined with increased confidence on the part of urologists about ultrasound images and corresponding reports, are responsible for the dramatic decline in requests for IVUs. However, when IVUs are requested, most radiologists make a conscious effort to keep the number of exposures to a minimum; indeed, many examinations are completed with one preliminary radiograph and a late-stage filling radiography (between 5 and 15 minutes). Radiologists find it helpful to review previous radiographs at the time of the study so that the imaging sequence can be tailored to the patient, thereby keeping the radiation dose as low as possible.



## Examinations Unique to the Pediatric Patient

### BONE AGE

Children can arrive at the imaging department with either retarded skeletal development or advanced skeletal maturation. In either situation the degree of skeletal maturation is determined by the appearance, size, and differentiation of various ossification centers. The most commonly used assessment technique, developed by Gruelich and Pyle,<sup>1</sup> compares an AP radiograph of the left hand and wrist with standards developed in the 1930s and 1940s and as later revised. Although these standards recognize the differing degrees of skeletal maturation between males and females by using separate standards for each gender, their applications are limited. Variations can also occur as a result of genetic diversity, nutritional status, and race.

Radiologists evaluate the differentiation and degree of fusion between the epiphyses and shafts of the bones of the hand and wrist by comparing the patient's radiograph with the standards printed in the atlas to determine the best match. The Gruelich and Pyle method is considered extremely useful for most ages. Little change occurs in the ossification centers of the hand and wrist in the first 1 to 2 years of life, whereas the ossification of the knee and foot occurs rapidly during this time. Therefore bone age protocols for children 1 and 2 years old often include an AP radiograph of the left knee. Some department protocols specify that a knee radiograph be included for all children under the age of 2 years. In dedicated pediatric centers, others have found it more practical to specify that if, on reviewing the radiograph, the radiographer notes an apparent lack of ossification in the metacarpal epiphyses, the necessary radiograph of the left knee should then be obtained.

<sup>1</sup>Gruelich WW, Pyle SI: *Radiographic atlas of skeletal development of the hand and wrist*, ed 2, Stanford, Calif., 1959, Stanford University Press.

### RADIOGRAPHY FOR SUSPECTED FOREIGN BODIES

#### Aspirated foreign body

A significant number of pediatric patients examined in emergency departments have a history that leads the physician to suspect a foreign body has been aspirated into the bronchial tree. This is a common cause of respiratory distress in children between the ages of 6 months and 3 years. In many cases the foreign body is nonopaque or radiolucent.

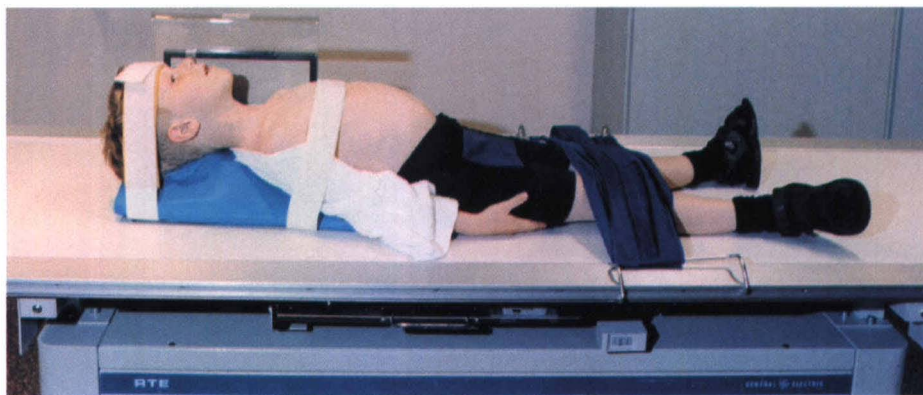
The foreign body, if slightly opaque and lodged in the *trachea*, may be demonstrated with filtered, high-kVp radiography of the *soft tissues of the neck*. From a radiologist's perspective, these images must be performed with the child's neck adequately extended and the shoulders lowered as much as possible. From the radiographer's perspective, this can be difficult to accomplish on the 6-month-old to 3-year-old. This challenge, however, is made easier with the use of the mc Infant Head and Neck Immobilizer.

#### Method

The radiographer observes the following guidelines:

- Have the child be undressed from the waist up. Then position the child with the head in the contoured/cut out portion, the neck over the raised portion, and the chest on the sloped portion of the immobility device (Fig. 28-39).
- Lower and immobilize the shoulders using the provided towlette; then immobilize the head and upper thorax using the foam-lined Velcro strips. The neck extension helps to keep the trachea from appearing buckled, and the towlette and foam-lined Velcro shoulder straps keep the shoulders from being superimposed on the airway.

The Infant Head and Neck Immobilizer is specially designed for radiography of the soft tissue of the neck. However, if the device is not available, the radiographer can improvise with a 45-degree sponge and some Velcro strips.



**Fig. 28-39** The mc Infant Head and Neck Immobilizer provides the necessary extension of the neck for radiography of the soft tissues of the neck. The shoulders are kept low with the use of a towlette.



Aspirated foreign bodies are *more commonly lodged in the bronchial tree*, more often in the right side than the left side. Air becomes trapped on the affected side because the lodged foreign body acts as a ball valve, permitting air to enter on inspiration but preventing it from being exhaled on expiration. The result is a relatively normal-appearing inspiratory PA chest image but an abnormal appearance on the expiratory radiograph. Consequently the *routine or protocol* for chest examinations in

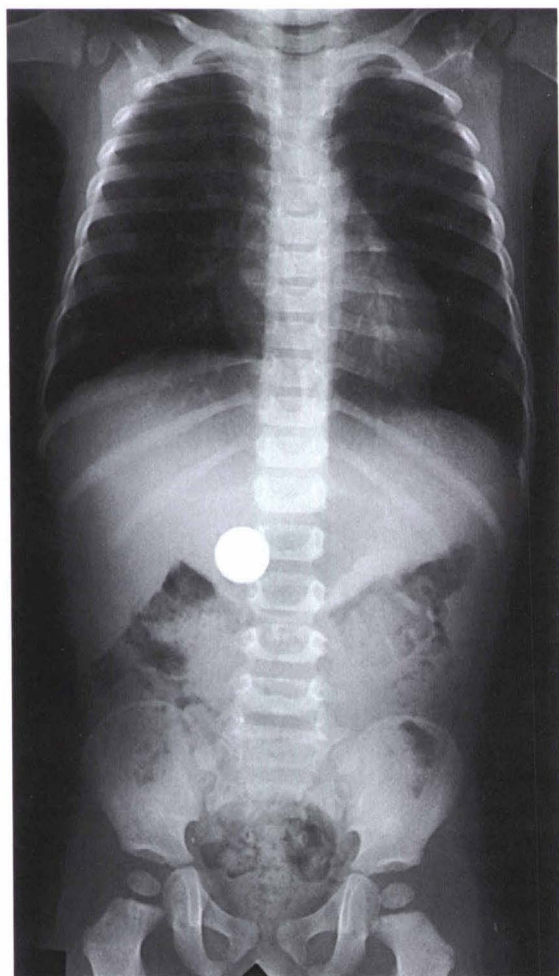
patients with suspected aspirated foreign bodies should be an *inspiratory PA projection*, an *expiratory PA projection*, and also a *lateral projection*. If satisfactory inspiration and expiration images cannot be obtained, bilateral lateral decubitus images should be obtained. (The unaffected lung will show that the heart has migrated toward the dependent lung. The affected dependent lung will remain fully inflated, preventing any downward migration of the heart.)

### Ingested foreign body

Children frequently put objects in their mouths. If swallowed, these objects can cause obstruction or respiratory distress. Coins are the most commonly ingested foreign body, and, being radiopaque, they are easily identified. When ingested foreign body is known or suspected, the first imaging examination should be radiographs of the neck and chest or radiographs of the nasopharynx, chest, and abdomen.

*Practical tip:* In small children (approximately 1 year of age), this examination can be performed using a 35 × 43 cm (14 × 17 inch) IR (Fig. 28-40). The radiographer needs to understand that the foreign body may be lodged anywhere between the nasopharynx and the anal canal. The presence of a foreign body cannot be ruled out if these areas are not well demonstrated. Esophageal studies are often required to demonstrate nonopaque foreign bodies.

Because of the anatomy of the esophagus and trachea, a coin identified in the coronal plane at the level of the thoracic inlet generally is lodged in the esophagus, whereas a coin found along the sagittal plane is generally lodged in the trachea.



**Fig. 28-40** A radiograph of the nasopharynx, chest, and abdomen is used to rule out the presence of a foreign body. If the coin this child had ingested had not been visible, a separate radiograph of the nasopharynx would have been obtained. Note that the diagonal placement of the gonadal shield over the distal pubic symphysis prevents the lower rectum from being obscured by lead.

## SCOLIOSIS

*Scoliosis* has been defined as “the presence of one or more lateral-rotatory curvatures of the spine.”<sup>1</sup> *Lateral* means toward the side, and *rotary* refers to the fact that the vertebral column rotates around its axis. Scoliosis can be a congenital or an acquired (e.g., posttrauma) condition. When physicians suspect scoliosis, radiographers evaluate for it using a PA or AP projection (preferably PA projection for a significant radiation exposure dose reduction. See Volume 1, Chapter 8, scoliosis projections for references) on a 3-foot-long IR of the entire spine. If the physician feels the curve has progressed to the point that further intervention is needed, a full scoliosis series is requested. The full scoliosis series should consist of 3-foot PA and lateral projections of the spine and probably right- and left-bending images (Fig. 28-41); (see also Figs. 8-149 and 8-150). A PA chest radiograph is included when the series is requested preoperatively. The purpose of the bending images is to assess or predict the degree of correction that can be obtained. The follow-up radiographic examination usually includes upright PA and lateral images.

<sup>1</sup>Silverman FN, Kuhn UP: *Caffey's pediatric x-ray diagnosis-an integrated approach*, St Louis, 1993, Mosby.

The radiographer should observe the following guidelines for obtaining the easiest and potentially most accurate method of accomplishing the bending images:

- Place the patient in the supine position on the radiographic table.
- Ask the patient to bend sideways as if reaching for the knees.
- Ensure that the ASIS remain equidistant to the table as the patient bends.
- Collimation and centering are crucial because the resultant image must include the first “normal” shaped (i.e., non-wedge-shaped) cervical or thoracic vertebra down to the crests of the ilia (see Fig. 28-41). (Experience has shown that curve progression usually stops coincident with the fusing of the epiphyses of the iliac crests.)
- The geometric measurements determine the degree of curvature. The selected method of treatment is determined in part by the measurement of the angles outlined.

## Radiation protection

Because scoliosis images are obtained relatively frequently to assess the progression of the curves, effective methods of radiation protection must be used:

- Obtain the 3-foot AP projection using breast shields (the AP is used as it allows for more stability of patient especially after surgery); alternatively, position the patient for the PA projection, with very careful placement of breast shields.
- Ensure that lead is draped over the patient's right breast tissue for the AP left-bending image, and vice versa.
- Protect gonads by placing a small lead apron at the level of the ASIS.



**Fig. 28-41** In planning corrective surgery, orthopedic surgeons generally observe the bending images as if looking at the patient's back. The structures to be demonstrated include the uppermost non-wedge-shaped vertebrae and the iliac crests.

## Overview of Advanced Modalities

It is beyond the scope of this chapter to discuss *all* the imaging advances that have had a recent impact on pediatric imaging. The following sections highlight some advances that have had a direct impact on previously established protocols or routines in general radiography.

### MAGNETIC RESONANCE IMAGING

MRI is perhaps the most dramatic and widespread technologic advancement in imaging. MRI quickly gained acceptance in the evaluation of most organ systems in the adult population. Its acceptance has been slower in pediatrics. This is somewhat ironic, considering that some of the advantages of MRI (enhanced contrast resolution, multiplanar capabilities, and lack of ionizing radiation) are crucial considerations in pediatric imaging.

The explanation for the slower acceptance of pediatric MRI lies in the length of an MRI examination. For example, a spinal MRI procedure may take from 60 to 90 minutes. During this time a child is required to remain still in an enclosed tunnel, hearing a loud and constant “hammering” noise that can be rather frightening. In a large proportion of the pediatric population, heavy sedation is often required to be able to complete an MRI examination. Conscious sedation is sometimes inadequate because the child can wake up during the scan. General anesthesia, with its risks and potential complications, is therefore needed. This being the case, MRI in young children may be a very serious and potentially risky procedure. Consequently the MRI staff needs enhanced skills to care properly for these patients. It is preferable if the direct patient care team includes pediatric anesthesiologists and nurses. In addition, just as the successful radiologist of the twenty-first century will probably need to be proficient at MRI, the radiographer must be similarly proficient at providing high-quality diagnostic MRI studies.

MRI is documented as the method of choice for evaluating such pediatric spinal cord abnormalities as *tethered cords*, *lipomyelomeningoceles*, *neoplasms*, *myelination*, and *congenital anomalies*. MRI has also proved advantageous to cardiologists and cardiac surgeons. Diagnoses previously suggested on chest radiographs are now confirmed for the cardiologist. Cardiac surgeons are better able to plan corrective surgeries because MRI scans demonstrate the sites and full extent of collateral vessels necessary for grafting procedures.

As experience with pediatric limb radiography increases, the radiographer can appreciate the difficulties the physician has in diagnosing certain types of fractures of the epiphyseal plates (Salter-Harris fractures). MRI can demonstrate, through cartilaginous structures, fractures that would otherwise be missed because these areas appear lucent on the standard radiograph. Elbow surgery can be less complex for the orthopedic surgeon who can first rule out additional Salter-Harris fractures with multiplanar MRI scans. These multiplanar images include coronal, axial, and sagittal images.

### MYELOGRAPHY

In imaging departments where MRI is available, the popularity of myelography has been steadily decreasing. This is especially true in the adult population but a relatively significant number of myelograms are still performed in pediatric centers. Neonatal patients, for example, sometimes develop a weakness in their upper limbs after traumatic births. If the neonate has been removed too aggressively during vaginal delivery, the nerves of the brachial plexus can be injured. If small, these tears may resolve of their own accord. Alternatively, they may worsen and require surgical repair. The diagnostic procedure of choice in this instance is a CT myelogram (see Chapter 25). After introducing a contrast medium into the subarachnoid space using a spinal needle, the radiographer performs a spinal CT scan. This scan shows any abnormal collections of contrast material where the nerve roots have been pulled. A cervical CT scan with special reconstructions in the sagittal, coronal, and oblique planes helps to visualize this condition best.

### COMPUTED TOMOGRAPHY

CT has recently become a routine diagnostic tool—one that more and more general radiographers are using. Pediatric patients present unique challenges, even to the seasoned CT technologist.

In the pediatric population, CT is useful in diagnosing congenital anomalies, assessing metastases, and diagnosing bone sarcomas and sinus disease; it has virtually replaced radiographic scanography. Young children have difficulty following the instructions needed for a diagnostic scan. Suggestions regarding approach and atmosphere were presented at the beginning of this chapter. Some basic technical tips are given here. As in the care of any pediatric patient, the role of the CT technologist is important in the success of the examination. The technologist must gain the respect and confidence of the young patient and the caregiver, if present.

The CT scanner itself is a very impressive piece of equipment, one that needs careful explanation to help allay the patient's fears. One of the most significant fears is claustrophobia. Techniques to reduce claustrophobia include the use of a television/VCR and music for entertainment (Fig. 28-42). Parent participation is often encouraged for the same reasons outlined previously in the chapter.

The advent of faster scanners and the introduction of helical scanning have significantly reduced scan times, thereby lessening patient anxiety. For example, a neck, chest, abdomen, and pelvic scan can now be completed in approximately 1 minute. However, patient preparation, the injection of IV contrast material, and the computer processing of images can bring the total time of this examination to 15 to 20 minutes.



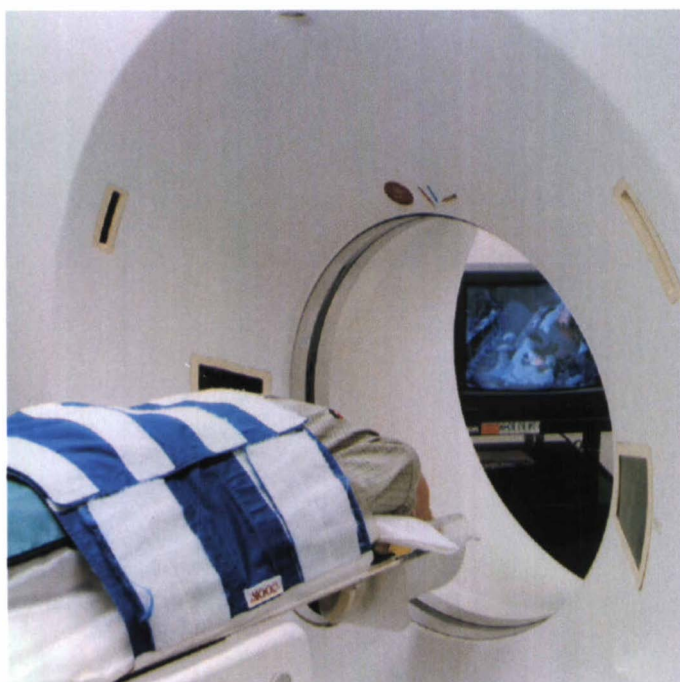
For young children, 15 or 20 minutes can be a long time, sometimes long enough to warrant the use of conscious sedation. Nursing staff then become actively involved in monitoring the sedated patient. The CT technologist should be comfortable with the use of oxygen-delivery systems, suction apparatus, and basic emergency management techniques. Generally speaking, if a reaction occurs in a pediatric patient, it will worsen significantly faster than in an adult. This underscores the need for the technologist to be well versed in the signs and symptoms of a potential reaction and the appropriate emergency response measures.

Emphasis should also be placed on mechanisms of dose reduction in CT. Examples include reducing the field of view (FOV) to allow precise collimation for the body part being examined and performing scans using preprogrammed (dose-conscious) protocols.

Technical advances in CT will bring even faster systems in the future. In fact, several manufacturers of CT scanners are currently advertising “real-time” CT. In practice this should reduce the number of patients requiring sedation, making the procedure faster, safer, and less costly. In addition to increasing scan speed, CT manufacturers have worked hard to include dose-minimizing software features and user-friendly protocol programming options. If optimized and used to their maximum potential, these features will make routine CT examinations easier, thereby opening the door of this specialty field to all technologists.

CT has largely replaced conventional radiographic examinations done to assess leg length discrepancy (LLD). *Spot scanography*, one of the relatively common conventional methods, is a technique in which three exposures of the lower limbs (centered over the hips, knees, and ankles in turn) are made on a single  $35 \times 43$  cm ( $14 \times 17$  inch) IR (see Chapter 11). A radiopaque rule is included for the purpose of calculating the discrepancy on the resulting image.

Studies have shown that CT digital radiography is an accurate technique for measuring LLD. It is reproducible, and positioning and centering errors are less likely to occur. More importantly, studies also report radiation dose to be less than that for conventional techniques, leading researchers to recommend that the CT scout image-type option be used particularly in young patients having serial examinations. Technical details beyond the scope of this atlas are provided in texts cited in the bibliography at the end of this chapter.



**Fig. 28-42** Right coronal CT positioning is best tolerated when patient is distracted by a television positioned behind the gantry.

### THREE-DIMENSIONAL IMAGING

In the pediatric population, three-dimensional images reconstructed from CT or MRI data have revolutionized surgical procedures. This new technique allows clinicians (predominantly orthopedic and plastic surgeons, but also neurosurgeons) to manipulate three-dimensional images of their patients interactively on a computer screen, rotating the image in any angle. Using this information, they can develop strategies that may change the complete treatment, management, or operative approach. Three-dimensional images are extremely useful, if not vital, in "mapping" a course of treatment for many corrective procedures for congenital malformations. Examples include craniofacial syndromes, congenital hip dysplasia, and conditions requiring plastic correction. Three-dimensional imaging also plays a major role in the management of cervical spine trauma and rotary subluxation of the spine in children.

### INTERVENTIONAL RADIOLOGY

Interventional radiology has dramatically changed the role of the radiology department in both teaching and nonteaching hospitals and clinics. In the past the justifications and rationales for radiology departments were diagnostic ones. However, radiology departments with professionally instructed interventional staff can now offer hospitals therapeutic services in addition to diagnostic services. This heightened awareness has largely resulted from the nature and efficacy of the interventional procedures.

These therapeutic interventions often obviate the need for surgery. Therapeutic procedures performed in the imaging department provide an attractive alternative to surgery for the patient, parent, hospital administrator, and society. (A procedure performed in the imaging department is much less expensive than one performed in the operating room.) These procedures are minimally invasive compared with their surgical counterparts, thereby reducing recovery times. Shortened length of stay translates into economic savings for the parents of pediatric patients.

Although these interventional procedures are predominantly performed in suites previously referred to as *specials* or *angiographic suites*, many procedures, especially nonvascular procedures, are performed in digital radiography and fluoroscopy suites. These diverse locations of care and the postprocedural care involved with vascular-interventional cases provide expanded avenues for general-duty radiographers to come in contact with patients. Interventional radiology holds a privileged position in many imaging departments. Nevertheless, a detailed, descriptive explanation of this role is well beyond the scope of this text. (Detailed discussions appear in texts cited in the bibliography at the end of this chapter for further readings.)

General radiographers must be able to recognize patients who have undergone interventional procedures, particularly vascular-interventional procedures in which central venous access devices have been inserted or implanted. This heightened awareness is crucial for infection prevention. After central venous access devices are inserted, they provide a direct conduit to the heart—a conduit or route in which bacteria can readily grow.

The following paragraphs provide a brief overview of some of the most common venous access devices and indications for their use. They also illustrate the need for increased education to prevent catheter-related infections. Although estimates regarding the rate of infection vary, health care professionals involved in the management of patients with indwelling vascular access devices do not minimize the magnitude and severity of catheter-related infections. They also are among the first to admit that "intravascular devices are indispensable in modern-day medical practice."<sup>1</sup> Catheter-related infections can increase the length of hospital stays and put patients at risk. However, as with radiologic procedures, the benefits often outweigh the associated risks.

<sup>1</sup>Pearson, ML: *Infect Control Hosp Epidemiol* 17:439, 1996.

Interventional radiology presents an alternative to pediatric surgery for angioplasty (balloon dilation), stent placement, embolization, vascular access device insertion, and numerous other procedures. *Angioplasty* refers to the placement of a balloon-tipped catheter in the center of a narrowed vessel; the balloon is inflated and deflated several times to stretch or dilate the narrowed segment. *Embolization* refers to the occlusion of small feeder vessels with either tiny coils or specially formulated glue. This procedure is performed to cut off the blood supply to a tumor.

For simplicity, interventional radiology can be divided into vascular and nonvascular procedures. Vascular procedures are generally performed in angiographic suites. In addition to the therapy (or intervention) being provided, angiography and ultrasonography are also performed for diagnostic and guidance purposes. Angiography can be arterial or venous; pediatric vasculature is well suited to both. IV injection is favored in infants because their relatively small blood volume and rapid circulation allow for good vascular images to be obtained after the injection of contrast material into a peripheral vein. In infants, hand injections are often preferred over power injections to help avoid extravasation. Intraarterial digital subtraction angiography (DSA) (see Chapter 35) has become a valuable tool for imaging professionals. DSA is performed using diluted contrast medium, which can reduce pain, and it provides a useful "roadmapping" tool. Roadmapping, a software tool available on newer angiographic equipment, uses the intraarterial injection to provide a fluoroscopic display of arterial anatomy—a very useful tool for imaging tortuous vessels.

Vascular-interventional procedures can be neurologic, cardiac, or systemic in nature. Nonvascular procedures often involve the digestive and urinary systems. Examples include the insertion of gastrostomy and nephrostomy tubes, respectively. These tubes provide conduits from the stomach and kidneys to the skin surface.



The following paragraphs focus on the vascular side of interventional radiology, more specifically the insertion of vascular access devices. The reason for this is simple: given the number of chest radiographs ordered for pediatric patients, radiographers will far more frequently encounter patients with these devices.

Simply stated, vascular access devices are of three types: nontunneled, tunneled, and implanted. The selection of device is often determined by a combination of factors, including the purpose of the access, and proposed indwelling time. Furthermore, the physician or patient may choose a particular device in the interests of compliance or after assessing underlying clinical considerations.

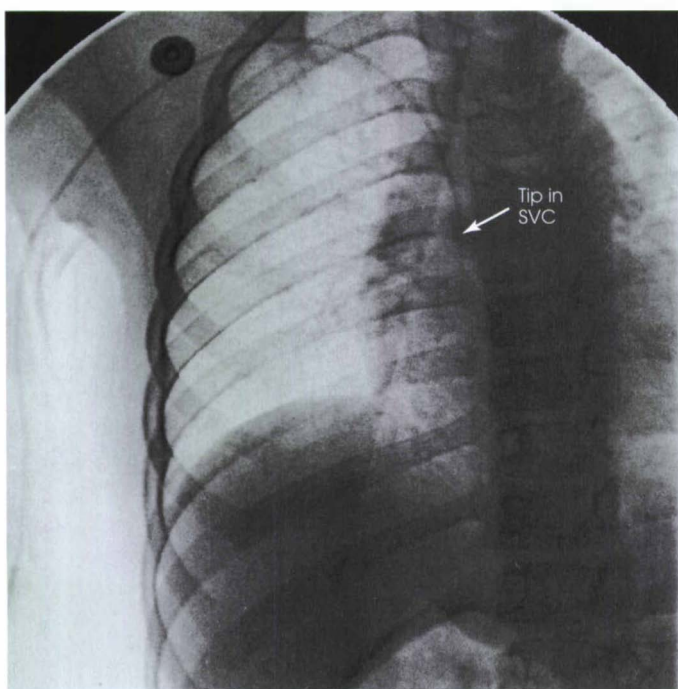
Nontunneled catheters are commonly referred to as *peripherally inserted central catheters*, or *PICC lines*. They are available with single or multiple lumens. The insertion point is usually the basilic or cephalic vein, at or above the antecubital space of the nondominant arm. Multiple lumens are desirable when a variety of different medications (including total parenteral nutrition) are to be administered (Fig. 28-43). These devices must be strongly anchored to the skin because children often pull on and displace the catheters, resulting in damage to the line and potential risk to themselves. To render the catheters more secure, pediatric clinicians often tailor their insertion and anchoring techniques to help prevent the catheter from being pulled out by the patient.

As with PICC lines, tunneled catheters can have multiple lumens. However, unlike PICC lines, they are not inserted into the peripheral circulation; rather, they are inserted via a subcutaneous tunnel into the subclavian or internal jugular veins. The tunneling acts as an anchoring mechanism for the catheter to facilitate long-term placement (Fig. 28-44). Tunneled catheters are used for the administration of chemotherapy, antibiotics, and fluids; they are also used for hemodialysis. (Technologists may see or hear these referred to as *Hickman lines*, a term that has been generalized to include tunneled catheters placed in subclavian or internal jugular veins.)

A



B



**Fig. 28-43** **A**, Postinsertion image of a double-lumen peripherally inserted central catheter (PICC) line in a 7-year-old boy (shown in the interventional suite). Conscious sedation was used for this procedure. **B**, Digital image of PICC line demonstrating the distal tip of the catheter positioned in the superior vena cava.



**Fig. 28-44** External appearance of tunneled, double-lumen central venous access device. These catheters are used for long-term therapy. Their short track to the heart can increase the risk of infection, necessitating proper care for maintenance.



Implanted devices are often referred to as *ports*. These are titanium or polysulfone devices with silicone centers, and they are attached to catheters. The whole device is implanted subcutaneously with the distal end of the catheter tip further implanted, often into the superior vena cava or right atrium. A port is the device of choice for noncompliant children or adults who, for aesthetic purposes, would rather not have the limb of a catheter protruding from their chest (Fig. 28-45).

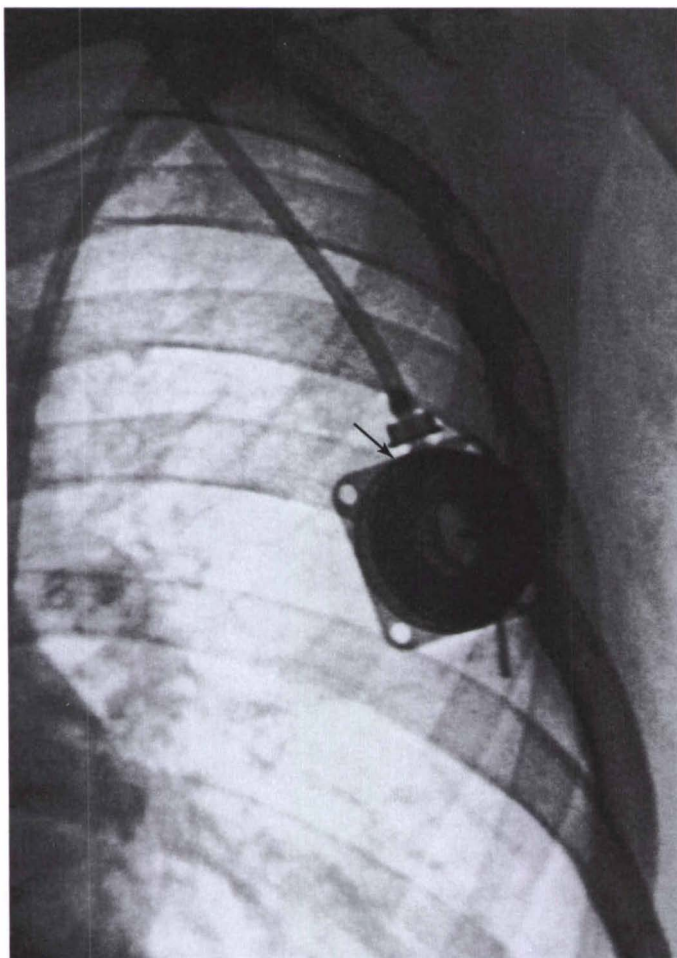
In summary, vascular access devices have dramatically changed the course of treatment for many patients in a very positive way. Patients who would have previously been hospitalized for antibiotic therapy can now go home with the device in place. This is good news. The increased prevalence of these devices means that patients with vascular access devices are in the community and visiting radiology departments everywhere. Therefore the need has grown for increased education for patients and those who come in contact with them. PICC lines have a smaller likelihood of introducing catheter-related infections; tunneled lines present a greater risk.

Radiographers must recognize vascular access devices and treat them with utmost care. They should report dislodged bandages and sites showing signs of infection (i.e., redness, exudate) *immediately*. Catheter-related infections compound recovery courses, sometimes in life-threatening ways. They cost hospitals many thousands of dollars each year.

Postprocedural care currently represents a very significant and ongoing challenge for all personnel who treat, manage, and come in contact with patients who have vascular access devices. To date, this challenge has not been adequately addressed. *To whom does the responsibility of postprocedural care rest?* It is the responsibility of all these personnel.

## NUCLEAR MEDICINE

If bladder function is the *only* concern for the physician who requests a VCUG, a nuclear medicine *direct radionuclide cystogram (DRC)* can be performed. The DRC emphasizes the assessment of bladder function. Radiographers should recognize that *nuclear medicine studies assess function rather than demonstrate anatomy*. The DRC permits observation of reflux during imaging over a longer period. In addition, it allows for accurate quantification of post-voiding residual volume. The radiation dose to the patient is less with this procedure than with the VCUG, making it an attractive option for the pediatric patient. (Technical details on nuclear medicine are presented in texts cited in the selected bibliography at the end of this chapter.)



**Fig. 28-45** Digital image of port (arrow). Ports are vascular devices that must be accessed subcutaneously. They are preferred for active children and for aesthetic reasons.

## Conclusion

Although no one can prevent a child from experiencing the fear engendered by a visit to the hospital, much can be done to allay that fear. Questions from children such as "Am I going to have a needle?" require a truthful response. However, the manner in which the response is delivered can make a tremendous difference. Children are impressionable and dependent on their caregivers, but they are also often the best teachers radiographers can have. Radiographers should watch and listen to these small patients, observe their body language and facial expressions, and note their questions and reactions for cues regarding ways to respond to them. The rewards—a child's smile and trust—are given more frequently than might be expected.

## Acknowledgment

The authors wish to acknowledge the contributions of GE Medical Systems Canada, Mississauga, Ontario, and Cook (Canada), Inc., Stouffville, Ontario, which made the color illustration portion for this chapter possible.

## Dedication

To the many children who have passed through the doors of the Hospital for Sick Children, and to those who will come in the future.

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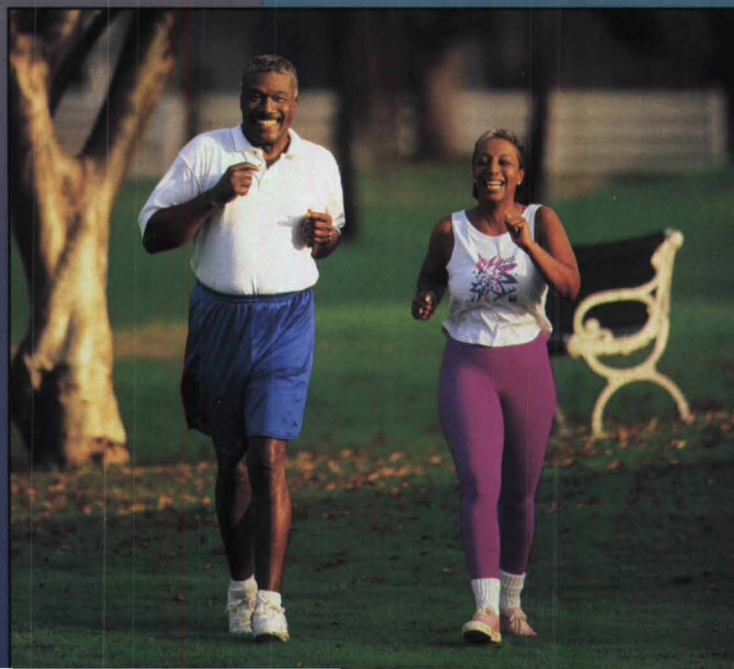
# GERIATRIC RADIOLOGY

CONNIE L. MITCHELL

Lifestyle factors such as diet, exercise, and smoking cessation reduce the risk of disease and increase life span.

## Outline

The radiographer's role, 220  
A special population, 220  
Physical, cognitive,  
and psychological effects  
of aging, 223  
Physiology of aging, 225  
Patient care of the elderly  
and the radiographer, 229  
Conclusion, 231



*Geriatrics* is the branch of medicine dealing with the aged and the problems of the aging. The ongoing increase in the numbers of elderly persons over age 65 in the U.S. population is well known. An even more dramatic aging trend exists among those older than 85 years of age. The number of people aged 100 is approximately 100,000 and increasing. Every aspect of the health care delivery system is affected by this shift in the general population. The 1993 Pew Health Commission Report noted that "aging of the nation's society and the accompanying shift to chronic care that is occurring foretell major shifts in care needs in which allied health professionals are major providers of services." As members of the allied health professions, radiographers are an important component of the health care system. As the geriatric population increases, so does the number of medical imaging procedures performed on the elderly. Students and practitioners must be prepared to meet the challenges that this dramatic shift in patient population represents. An understanding of geriatrics will foster a positive interaction between the radiographer and the elderly patient.

## The Radiographer's Role

The role of the radiographer is no different than that of all other health professionals. The whole person must be treated, not just the manifested symptoms of an illness or injury. Medical imaging and therapeutic procedures reflect the impacts of ongoing systemic aging in documentable and visual forms. Adapting procedures to accommodate disabilities and diseases of geriatric patients is a critical responsibility and a challenge based almost exclusively on the radiographer's knowledge, abilities, and skills. An understanding of the physiology and pathology of aging, in addition to an awareness of the social, psychological, cognitive, and economics of aging are required to meet the needs of the elderly population. There are conditions typically associated with elderly patients that invariably require adaptations or modifications of routine imaging procedures. The radiographer must be able to differentiate between age-related changes and disease processes. Production of diagnostic images requiring professional decision making to compensate for physiological changes, while maintaining the compliance, safety, and comfort of the patient, is the foundation of the contract between the elderly patient and the radiographer.

## A Special Population DEMOGRAPHICS AND SOCIAL EFFECTS OF AGING

The acceleration of the "gray" American population began when those individuals born between 1946 and 1964 known as the "baby boomers" began to turn age 50 in 1996. The number in the age 65 and older cohort is expected to reach 70.2 million by 2030 (Fig. 29-1). The United States experience regarding the increase in the elderly population is not unique; it is a global one. As of 1990, 28 countries had more than two million persons older than 65 and 12 additional countries had more than five million people. The entire elder population of the world has begun a predicted dramatic increase for the period from 1995 to 2030.

Research on a wide variety of topics ranging from family aspects of aging, economic resources, and the delivery of long-term care states that gender, race, ethnicity, and social class have consistently influenced the quality of the experience of aging. The experience of aging results from interaction of physical, mental, social, and cultural factors. Aging varies across cultures. Culturally, aging, as well as the treatment of the elderly, is often determined by the values of an ethnic group.

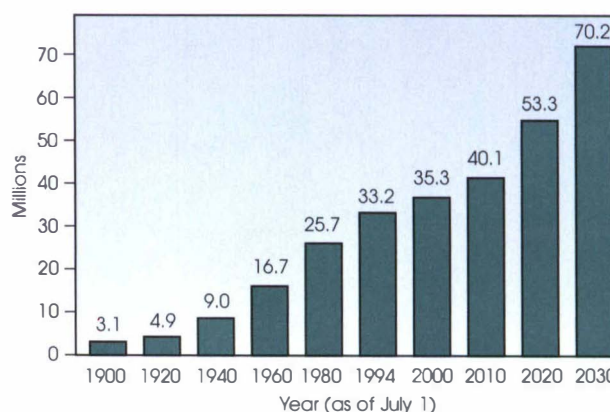


Fig. 29-1 Number of persons in millions 65+; 1900 to 2030.

(Reprinted from *65+ in the United States*, U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census, Washington, DC, 1996.)



Culture also may determine the way the older person views the process of aging, as well as the manner in which he or she adapts to growing older. A more heterogeneous elderly population can be expected than any generation that preceded it. This is a result of both increasing immigration from noncaucasian countries and a lower fertility/reproductive rate among the Caucasian population. This group will contain a mix of cultural and ethnic backgrounds. The United States is a multicultural society in which a generalized view of aging in America would be difficult. *Health care professionals will not only need to know diseases and disorders common to a specific age group, but will need to know a particular ethnic group as well.* An appreciation of diverse backgrounds can help the health care professional provide a personal approach when dealing with and meeting the needs of elderly patients. Many universities are incorporating cultural diversity into their curriculum.

The *economic status* of the elderly is varied and an important influence on their health and well being (Fig. 29-2). The majority of older people have an adequate income, but a substantial number of minority patients do not. Single elders are more likely to be below the poverty line. Economic hardships increase for single elders, especially women. Sixty percent of the population over age 85 is women, making them twice as likely as men to be poor. By age 75, nearly two thirds of women are widows. Financial security is extremely important to an elderly person. Many elderly people are reluctant to spend money on what others may consider necessary for their well being. A problem facing the American aging society is health care finances. Individuals in this situation will often make decisions regarding their care, not based on their needs, but based exclusively on the cost of those services. (An increase in health care and the aging population go hand and hand.) Heart disease, cancer, and stroke account for 7 of every 10 deaths among people older than 65. It is estimated that by the year 2025, two thirds of the U.S. health care budget will be devoted to services for the elderly.



**Fig. 29-2** The economic status of the elderly is varied and an important influence on their health and well-being.



Aging is a broad concept that includes physical changes in our bodies over adult life, psychological changes in our minds and mental capacities, social psychological changes in what we think and believe, and social changes in how we are viewed, what we expect, and what is expected of us. It is a constantly evolving concept. There are valid notions that biological age is more critical than chronological age when determining health status of the elderly. Aging is an individual and extremely variable process. The functional capacity of major body organs varies with advancing age. As one grows older, environmental and lifestyle factors affect the age-related functional changes in the body organs. Advancements in medical technology have extended the average life expectancy in the United States by nearly 20 years over the past half-century, which has allowed senior citizens to be actively involved in every aspect of American society. People are healthier longer today because of advanced technology, the results of health promotion and secondary disease prevention and lifestyle factors such as diet, exercise, and smoking cessation have been effective at reducing the risk of disease (Fig. 29-3).

The majority of the elderly seen in the health care setting have been diagnosed with at least one chronic condition. Individuals, who in the 1970s would not have survived a debilitating illness, such as cancer or a catastrophic health event such as a heart attack, are now able to live for more extended periods of time, sometimes with a variety of concurrent debilitating conditions. Although age is the most consistent and strongest predictor of risk for cancer and for death from cancer, management of the elderly cancer patient becomes complex as other chronic conditions such as osteoarthritis, diabetes, chronic obstructive pulmonary disease (COPD), and/or heart disease must also be considered in their care. Box 29-1 lists the top ten chronic conditions for people older than 65.

The attitudes of health care providers toward older adults impact their health care. It is unfortunate that research indicates health care professionals are significantly more negative in their attitudes toward older patients than younger ones. This attitude must change if the health care provider is to have a positive interaction with the elderly patient. These attitudes appear to be related to the pervasive stereotyping of the elderly, which serves to justify avoiding care and contact with them, as well as being reminders of our own mortality. *Ageism* is a term used to describe the stereotyping of and discrimination against elderly persons and is considered to be similar to that of racism and sexism. It emphasizes that frequently the elderly are perceived to be repulsive and that a distaste for the aging process itself exists. Ageism suggests that the majority of elderly are senile, miserable most of the time, and dependent rather than independent individuals. The media have also influenced ongoing stereotypical notions about the elderly. Commercials target the elderly as consumers of laxatives, wrinkle creams, and other products that promise to prolong their condition of being younger, more attractive, and desirable. Television sitcoms portray the elderly as stubborn and eccentric. Health care providers must learn to appreciate the positive aspects of aging so they can assist the elderly in having a positive experience with their imaging procedure.



**Fig. 29-3** Lifestyle factors such as diet, exercise, and smoking cessation reduce the risk of disease and increase life span.

#### BOX 29-1

Top ten chronic conditions of people older than 65

- Arthritis
- Hypertension
- Hearing impairment
- Heart disease
- Cataracts
- Deformity or orthopedic impairment
- Chronic sinusitis
- Diabetes
- Visual impairment
- Varicose veins

A 1995 study by Rarey concluded that a large majority of the 835 radiographers surveyed in California were not well informed about gerontological issues and were not prepared to meet the needs of their patients over age 65.<sup>1</sup> Rueters Health reported from a Johns Hopkins study that medical students generally have poor knowledge and understanding of the elderly, and this translates to an inferior quality of care for older patients. More education in gerontology is necessary for radiographers and even physicians. Education will enable them to adapt imaging and therapeutic procedures to accommodate mental, emotional, and physiological alterations associated with aging; and to be sensitive to cultural, economic, and social influences in the provision of care for the elderly.

<sup>1</sup>Rarey LK: Radiologic technologists' responses to elderly patients. *Radiol Tech* 69(6):566, 1996.

## Physical, Cognitive, and Psychological Effects of Aging

The human body undergoes a multiplicity of physiological changes second by second.

Little consideration is given regarding these changes unless they are brought on by sudden physical, psychological, or cognitive events. It is important for radiographers to remember that each elderly person we encounter is a unique individual with distinct characteristics. These individuals have experienced a life filled with memories and accomplishments.

Young or old, the definition of quality of life is an individual and personal one. Research has shown that health status is an excellent predictor of happiness. Greater social contact, health satisfaction, low vulnerable personality traits, and fewer stressful life events have been linked to successful aging. Self-efficacy can be defined as the level of control one has over one's future. Many elderly people feel they have no control over medical emergencies and fixed incomes. Many have fewer choices about their personal living arrangements. These environmental factors can lead to depression and decreased self-efficacy. An increase in illness will usually parallel a decrease in self-efficacy.

A positive attitude is a very important aspect of aging. Many older people have the same negative stereotypes about aging that young people do.<sup>1</sup> For them, feeling down and depressed becomes a common consequence of aging. One of five people older than age 65 in a community will show signs of clinical depression. Yet we, as health care professionals, know that depression can affect both young and old. In general, research has shown the majority of elderly people rate their health status as good to excellent. How elderly persons perceive their health status largely depends on their successful adaptation to disabilities. Radiographers need to be sensitive to the fact that an elderly person may have had to deal with a number of losses, both social and physical, in a very short period of time. More importantly, they must recognize symptoms resulting from these losses in order to communicate and interact effectively with this patient population.

Although, as health care providers, the radiographer's contribution to a patient's quality of life may be minimal, it is not insignificant. It is necessary to remember that each elderly person is unique and deserves respect for his or her own opinions.

<sup>1</sup>Rowe JW, Kahn RL: *Successful aging*. New York, 1998, Dell Publishing.



The aging process alone does not likely alter the essential core of the human being. Physical illness is not aging and age-related changes in the body are often very modest in magnitude. As one ages, the tendencies to prefer slower paced activities, take longer to learn new tasks, become more forgetful, and lose portions of sensory processing skills increase slowly but perceptibly. We need to be reminded that *aging and disease are not synonymous*. The more closely a function is tied to physical capabilities, the more likely it is to decline with age, whereas the closer a function depends on experience, the more likely it will increase with age.

Box 29-2 lists the most common health complaints of the elderly.

Joint stiffness, weight gain, fatigue, and loss of bone mass can be slowed through proper nutritional interventions and low-impact exercise. The importance of exercise cannot be overstated. Exercise has been shown to increase aerobic capacity and mental speed. Exercise programs designed for the elderly should emphasize increased strength, flexibility, and endurance. One of the best predictors of good health in later years is the number and extent of healthy lifestyles that were established in earlier life.

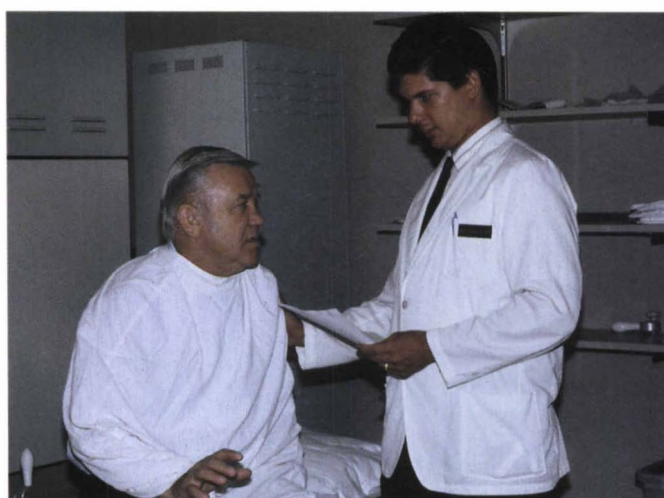
#### BOX 29-2

##### Most common health complaints of the elderly

Weight gain  
Fatigue  
Loss of bone mass  
Joint stiffness  
Loneliness

The elderly person may show decreases in attention skills during complex tasks. Balance, coordination, strength, and reaction time all decrease with age. Falls associated with balance problems are common in the elderly population, resulting in a need to concentrate on walking. *It is helpful not to overwhelm them with instructions*. Their hesitation to follow instructions may be a fear installed from a previous fall. Sight, hearing, taste, and smell are all sensory modalities that decline with age. Older people have more difficulty with bright lights and tuning out background noise. Many elderly become adept at lip reading to compensate for loss of hearing. It is not unusual for radiographers to assume all elderly patients are hard of hearing. They are not. Talking in a normal tone while making volume adjustments only if needed is a good rule of thumb. Speaking slowly, directly, and distinctly in giving instructions allows older adults an opportunity to sort through directions and improves their ability to follow them with better accuracy (Fig. 29-4).

Cognitive impairment in the elderly can be caused by disease, aging, and disuse. Dementia is defined as progressive cognitive impairment that eventually interferes with daily functioning. It includes cognitive, psychological, and functional deficits, including memory impairment. With normal aging comes a slowing down and a gradual wearing out of bodily systems, but it does not include dementia. Yet the prevalence of dementia increases with age. Persistent disturbances in cognitive functioning, including memory and intellectual ability, accompany dementia. *Fears of cognitive loss, especially Alzheimer's disease, are widespread among older people*. Alzheimer's disease is the most common form of dementia. Therefore health care professionals are more likely to encounter people with this type. The majority of elderly people work at maintaining and keeping their mental functions by staying active through mental games and exercises, and keeping engaged in regular conversation. When caring for patients with any degree of dementia, verbal conversation should be inclusive and respectful. One should never discuss them as though they were not in the room, nor not an active participant in the procedure.



**Fig. 29-4** Speaking slowly, directly, and distinctly in giving instructions allows older adults an opportunity to sort through directions and improves their ability to follow them with better accuracy.



One of the first questions asked of any patient entering a health care facility for emergency service is, "Do you know where you are and what day it is?" The health care providers need to know just how alert the patient is. Although memory does decline with age, this is experienced mostly with short-term memory tasks. Long-term memory or subconscious memory tasks show little change over time and with increasing age. There can be a variety of reasons for confusion or disorientation. Medication, psychiatric disturbance, or retirement can confuse the patient. Retirement to some older people means creating a new set of routines and adjusting to them. The majority of elders like structure in their lives and have familiar routines for approaching each day.

## Physiology of Aging

Health and well being largely depends on the degree to which organ systems can successfully work together to maintain internal stability. It is apparent that with age, there is a gradual impairment of these homeostatic mechanisms. Elderly people experience non-uniform gradual, ongoing organ function failure in all systems. Many of the body organs gradually lose strength with advancing age. These changes place the elderly at risk for disease or dysfunction especially in the presence of stress. At some point the likelihood of illness, disease, and death increases. Various physical diseases and disorders affect both the mental and physical health of people of all ages. They are more profound among elderly people because diseases and disorders among older people are more likely to be chronic in nature. *Although aging is inevitable, the aging experience is highly individual and is affected by heredity, lifestyle choices, physical health, and attitude.* A great portion of usual aging risks can be modified with positive shifts in lifestyle.

## AGING OF THE ORGAN SYSTEMS

### Integumentary system disorders

The integumentary system is one of the first apparent signs of aging. With age comes flattening of the skin membranes making it vulnerable to abrasions and blisters. The number of melanocytes decreases making ultraviolet light more dangerous and the susceptibility to skin cancer increases. Wrinkling and thinning skin are very noticeable among the elderly. This is attributable to decreases in collagen and elastin in the dermis. There is a gradual loss of functioning sweat glands and skin receptors, which increases the threshold for pain stimuli, making the elderly person vulnerable to heat strokes. With age comes atrophy or thinning of the subcutaneous layer of skin in the face, back of the hands, and soles of the feet. Loss of this "fat pad" can cause many foot conditions in the elderly. The most striking age-related changes to the integumentary system are the graying, thinning, and loss of hair. With age, the number of hair follicles decreases and those follicles that remain grow at a slower rate with less concentration of melanin, causing the hair to become thin and white. A major problem with aging skin is chronic exposure to sunlight. The benefits of protecting one's skin with sunscreen and protective clothing cannot be overemphasized and will be more evident as one grows older.

### Nervous system disorders

The nervous system is the principle regulatory system of all other systems in the body. It is probably the least understood of all body systems. Central nervous system disorders are one of the most common causes of disability in the elderly accounting for almost 50% of disability in those older than age 65. Loss of myelin in axons in some of the nervous system contributes to the decrease in nerve impulse velocity that is noted in aging. Like any other organ system, the nervous system is vulnerable to the effects of atherosclerosis with advancing age. When blood flow to the brain is blocked, brain tissue is damaged. Repeated episodes of cerebral infarction can eventually lead to multi-infarct dementia. Changes in the blood flow and oxygenation to the brain slows down the time to carry motor and sensory tasks requiring speed, coordination, balance, and fine motor hand movements. This decrease in the function of motor control puts the elderly person at a higher risk for falls. Healthy changes in lifestyles can reduce the risk of disease. High blood pressure, for example, is a noted risk and can be decreased with medication, weight loss, proper nutritional diet, and exercise.

### Sensory system disorders

All of the sensory systems undergo changes with age. Beginning around the age of 40, the ability to focus on near objects becomes increasingly difficult. The lens of the eye becomes less pliable, starts to yellow, and becomes cloudy resulting in farsightedness (presbyopia); distorted color perception and cataracts also begin. Changes in the retina affect the ability to adapt to changes in lighting and there are decreased abilities to tolerate glare, making night vision more difficult for the elderly.

Hearing impairment is very common in the elderly. The gradual progressive hearing loss of tone discrimination is called presbycusis. Men are affected more often than are women and the degree of loss is more severe for high-frequency sounds. Speech discrimination is problematic when in noisy surroundings such as a room full of talking people.

There is a decline in sensitivity to taste and smell with age. The decline in taste is consistent with a decreased number of taste buds on the tongue, decreased saliva, and dry mouth that accompanies the aging process. Hyposmia, the impairment of the ability to smell, accounts for much of the decreased appetite and irregular eating habits consistently noted in the elderly. Similar to taste, the degree of impairment varies with a particular odor and the ability to identify odors in a mixture is gradually lost with age.

### Musculoskeletal system disorders

Musculoskeletal dysfunction is the major cause of disability in the elderly. Osteoporosis, reduction in bone mass and density, is one of the most significant age-related changes. Risk factors for osteoporosis include estrogen depletion, calcium deficiency, physical inactivity, testosterone depletion, alcoholism, and cigarette smoking. The rate of new bone resorption surpasses the rate of new bone formation at about age 40. This accounts for a subsequent loss of 40% bone mass in women and 30% bone mass in men over the course of the life span. The incidence of degenerative joint disease, osteoarthritis, increases with age. The weight-bearing joints are the most commonly affected, and obesity is probably the most important single risk factor. Osteoarthritis of the joint cartilage causes pain, swelling, and a decrease in range of motion in the affected joint. Osteoarthritis is the second most common cause of disability in this country, affecting more than 50 million Americans. At age 40, most adults have osteoarthritic changes visible on radiographic images of the cervical spine. The most progressive changes occur in weight-bearing joints and hands as age increases.

With age, women are more likely to store fat in their hips and thighs where men store fat in their abdomen area. Without exercise, muscle mass declines resulting in decreased strength and endurance, prolonged reaction time, and disturbed coordination. It cannot be over emphasized that regular physical training can improve muscle strength and endurance, along with cardiovascular fitness, even in the very old.

### Cardiovascular system disorders

The cardiovascular system circulates the blood, which delivers oxygen and nutrients to all parts of the body and removes waste products. Therefore damage to this system can have negative implications for the entire body. Decreased blood flow to the digestive tract, liver, and kidneys affects the absorption, distribution, and elimination of substances such as medications and alcohol.

Cardiovascular disease is the most common cause of death worldwide. The maximum heart rate during exercise decreases with age, thus the elderly become short of breath and tire quickly. Loss of arterial elasticity results in increased systolic blood pressure, increasing the risk for heart disease and stroke. Another prevalent problem is postural hypertension in which there is a fall in systemic blood pressure when rising from supine to standing position. The predominate change that occurs in the blood vessels with age is atherosclerosis, a development of fatty plaques in the walls of the arteries. These fatty plaques within the artery wall can lead to ulcerations of the artery wall subsequently making the artery prone to the formation of blood clots. The plaques also cause destruction of the artery wall, causing it to balloon, increasing the risk of an aneurysm. Complications can lead to an embolism, heart attack, or stroke. Preventive health measures such as control of high blood pressure, diet, exercise, and smoking cessation decrease the risk of cardiovascular disease. These interventions are more effective if initiated early in life.

### Gastrointestinal system disorders

Gastrointestinal disorders in the elderly can include malignancies, peptic ulcer disease, gastrointestinal bleeding, pancreatitis, difficulty swallowing, diverticulitis, gastric outlet obstruction, esophageal foreign bodies, constipation, and fecal incontinence. Mouth and teeth pain, side effects of medication, decreased saliva, and dry mouth can lead to nutritional deficiencies, malnutrition, and dehydration problems. The majority of gastrointestinal disorders are related to an age-related decrease in the rate of gastric acid production and secretions, as well as decreased motility of the smooth muscle in the large intestine. A decrease in acid production and secretion can lead to iron-deficiency anemia, peptic ulcers, and gastritis. Diverticulosis, a common problem in the elderly, develops when the large intestine herniates through the muscle wall. Gallstone disease, hepatitis, and dehydration tend to be more common in the older population. Healthy lifestyle habits such as smoking cessation, low alcohol intake, high fiber—low sugar diet, and regular exercise can decrease the risk of gastrointestinal problems. The secret to survival for colon and rectal cancer lies in inexpensive early detection. Stool samples and rectal examinations are very effective in detecting early cancer.

### Immune system decline

Age takes its toll on the immune system. To be immune to an infection implies protection from that infection. The ability of our body to remain free of infections requires the immune system to distinguish our own healthy cells from invading microorganisms or altered cancer cells. The age-related decline of the immune system functioning makes the elderly more vulnerable to diabetes mellitus, pneumonia, and nosocomial infections. The incidence of infectious disease rises in adulthood. Prevalent among the aged would be influenza, pneumonia, tuberculosis, meningitis, and urinary tract infections. The three general categories of illness that preferentially afflict the elderly are infections, cancer and autoimmune disease.<sup>1</sup>

<sup>1</sup>Chop WC, Robnett RH: *Gerontology for the health care professional*, Philadelphia, 1999, FA Davis.



### Respiratory system disorder

Throughout the aging process, the lungs lose some of their elastic recoil trapping air in the alveoli. This decreases the rate of oxygen entering the blood stream and the elimination of carbon dioxide. The muscles involved in breathing become a little more rigid, which can account for shortness of breath with physical stress. In the wall of the thorax, the rib cage stiffens, causing kyphotic curvature of the thoracic spine. Respiratory diseases that increase in frequency with aging include emphysema, chronic bronchitis, pneumonia, and lung cancer. There is a strong association between low lung function and the future development of coronary heart disease. Research has shown that the total amount of air inhaled in one's deepest breath and the fastest rate at which one can exhale are powerful predictors of how many more years one will live. Sedentary lifestyle is the greatest risk factor in lung function and lifestyle habits are the critical factors in which we have control.

### Hematological system disorders

A major hematological concern in the elderly is the high prevalence of anemia. Individuals with anemia often have pale skin, shortness of breath, and fatigue easily. As bone ages, the marrow of the bone has a harder time maintaining blood cell production than young bone marrow when the body is stressed. It is felt that the high incidence of anemia in the elderly is not a result of aging per se but rather to the high frequency of other age-related illnesses that can cause anemia. Anemia is not a single disease but a syndrome that has several different causes. Insufficient dietary intake and inflammation or destruction of the gastrointestinal lining to absorb vitamin B<sub>12</sub>, causes a type of anemia that afflicts the elderly. Because of other physiological stresses affecting marrow production, the elderly have an increased incidence of a variety of blood disorders.

### Genitourinary system disorders

Familiar age-related genitourinary (GU) changes are those associated with incontinence. Changes in bladder capacity and muscle structure predispose the elderly to this problem. Along with these structural changes in the GU system the number of nephrons in the kidneys decrease dramatically following the onset of adulthood. This decreased reserve capacity of the kidneys could cause what would otherwise be a regularly prescribed dose of medication to be an overdose in the elderly. The role of the kidneys to maintain the body's water balance and regulate the concentration according to the body's need diminishes with age. Acute and chronic renal failure can affect many elderly in their later years.

## Endocrine system disorders

The endocrine system is another principle regulatory system of the body. Age-related changes in the thyroid function results from inadequate responses of target cells to thyroid hormone. The most common age-related disease associated with the endocrine system is diabetes mellitus. Non-insulin dependent diabetes mellitus increases in frequency with age and accounts for about 90% of all cases. Regular exercise and weight loss can significantly reduce the risk and delay the onset of non-insulin-dependent diabetes.

*Aging is the one certainty in life.* It starts at conception and continues throughout the life cycle. No one person ages in the same way. As stated earlier, it is very individualized and is affected by heredity, lifestyle choices, physical health, and attitude. Despite the changes that occur in the body systems observed with aging, the majority of older adults view themselves as healthy. They learn to adapt, adjust, and compensate for these disabilities. *Older people are stereotyped into two groups: the diseased and the normal.* The normal group is in fact at high risk of disease, just not there yet. While categorizing them as normal, we underestimate their vulnerability. The fact is, modest increases in blood pressure, blood sugar, body weight, and low bone density are common among the normal elderly. These risk factors promote disease, and yet they can be modified. They may be age-related in industrial societies, but they are not age-determined or harmless. The power of lifestyle factors such as diet, exercise, and smoking cessation reduces the risk of disease and improves the quality of life. Good health cannot be left to chance and staying healthy depends to a large degree on lifestyle choices and attitude.

## Patient Care of the Elderly and the Radiographer

Box 29-3 lists some quick tips for working with the elderly. These tips are discussed in the context following the table.

### PATIENT AND FAMILY EDUCATION

Education about imaging procedures to obtain their confidence and compliance is crucial for all patients, especially for elderly patients. More time with the elderly patient may be necessary to accommodate their decreased ability to rapidly process information. The majority of elderly have been diagnosed with at least one chronic illness. They typically arrive at the clinical imaging environment with a natural anxiety because they are likely to have little knowledge of the procedure or the highly technical modalities employed for their procedures. Moreover, a fear concerning consequences resulting from the examination exacerbates their increased levels of anxiety. Taking time to educate patients and their families or significant caregivers in their support system about the procedures makes for a less stressful experience and improved patient compliance and satisfaction.

## COMMUNICATION

Good communication and listening skills create a connection between the radiographer and his or her patient. Older people are unique and should be treated with dignity and respect. Each elderly person is a wealth of cultural and historical knowledge that in turn becomes a learning experience for the radiographer. If it is evident that the patient cannot hear or understand verbal directions, it is appropriate to speak lower and closer. Background noise can be disrupting to an older person and should be eliminated if possible when giving precise instructions. Giving instruction individually gives the elder person time to process your request. An empathetic, warm attitude and approach to the geriatric patient will result in a trusting and compliant patient.

### BOX 29-3

#### Tips for working with the elderly patient

- Take time to educate the patient and his or her family
- Speak lower and closer
- Treat the patient with dignity and respect
- Give the patient time to rest between projections and procedures
- Avoid adhesive tape: elderly skin is thin and fragile
- Provide warm blankets in cold examination rooms
- Use table pads and hand rails
- Always access the patient's medical history before contrast media is administered

## TRANSPORTATION AND LIFTING

Balance and coordination of the elderly patient can be affected by normal aging changes. Their anxiety about falling can be diminished by assistance in and out of a wheelchair, and to and from the examination table. Many elderly have decreased height perception resulting from some degree of vision impairment. Hesitation of the elder person may be as a result of previous falls. Assisting them when there is a need to step up or down throughout the procedure is more than a reassuring gesture. Preventing opportunities for falls is a necessity for the radiographer. The elderly patient will often experience vertigo and dizziness when going from a recumbent position to a sitting position. Giving the patient time to rest between positions will mitigate these disturbing, frightening, and uncomfortable sensations. The use of table handgrips and proper assistance from the radiographer creates a sense of security for the elderly patient. A sense of security will result in a compliant and trusting patient throughout the imaging procedure.

## SKIN CARE

Acute age-related changes in the skin will cause it to become thin and fragile. The skin becomes more susceptible to bruising, tears, abrasions, and blisters. All health care professionals should use caution in turning and holding the elderly patient. Excessive pressure on the skin will cause it to break and tear. *Adhesive tape should be avoided since it can be irritating and can easily tear the skin of an older person.* The loss of fat pads makes it painful for the elderly patient to lie on a hard surface and can increase the possibility of developing ulcerations. Almost without exception tables used for imaging procedures are hard surfaced and cannot be avoided. However, the use of a table pad can reduce the friction between the hard surface of the table and the patient's fragile skin. Sponges, blankets, and positioning aids will make the procedure much more bearable and comfortable for the elderly patient. Because skin plays a critical role in maintaining body temperature, the increasingly thinning process associated with aging skin renders the patient less able to retain normal body heat. Thus the regulation of body temperature of the elderly person varies from that of a younger person. To prevent hypothermia in rooms where the ambient air temperature is comfortable for the radiographer, it may be essential to provide blankets for the elderly patient.

## CONTRAST ADMINISTRATION

Because of age-related changes in kidney and liver functions only the amount, not the type, of contrast media is varied when performing radiographic procedures on the elderly patient. The number of functioning nephrons in the kidneys steadily decreases from middle age throughout the life span. Compromised kidney function contributes to the elderly patient being more prone to electrolyte and fluid imbalance, which can create life-threatening consequences. They are also more susceptible to effects of dehydration because of diabetes and/or decreased renal or adrenal function. The decision of type and amount of contrast media used for the geriatric patient usually follows some sort of routine protocol. Assessment for contrast agent administration accomplished by the imaging technologist must include age and history of liver, kidney, or thyroid disease; history of hypersensitivity reactions and previous reactions to medications or contrast agents; sensitivity to aspirin; over-the-counter and prescription drugs history, including acetaminophen (Tylenol); and history of diabetes and hypertension.<sup>1</sup> The imaging technologist must be selective in locating an appropriate vein for contrast administration on the elderly patient. They should consider the location and condition of the vein, decreased integrity of the skin, and the duration of the therapy. Thin superficial veins, repeatedly used veins, and veins located in areas where the skin is bruised and/or scarred should be avoided.

<sup>1</sup>Norris T: *Special needs of geriatric patients*. American Society of Radiologic Technologists Homestudy Series Volume 4:5, 1999.



## JCAHO CRITERIA

The Joint Commission on the Accreditation of Healthcare Organizations (JCAHO) is the accrediting and standards-setting body for hospitals, clinics, and other health care organizations in the United States. Employees in institutions accredited by the JCAHO must demonstrate age-based communication competencies, which include the elderly. The standards were adopted as a means of demonstrating competence in meeting the physiological and psychological needs of patients in special populations. These populations include infants, children, adolescents, and the elderly.

Standard HR.5 of the Human Resources section of the JCAHO manual states, "When appropriate, the hospital considers special needs and behaviors of specific age groups in defining qualifications, duties, and responsibilities of staff members who do not have clinical privileges but who have regular clinical contact with patients (for example radiologic technologists and mental health technicians)." The intent of the standard is to ensure age-specific competency in technical and clinical matters but is not limited to equipment and technical performance. Knowledge of age-related changes and disease processes assist all health care professionals, including those in the radiation sciences, in providing care that meets the needs of the elderly patient.

## Conclusion

The imaging professional will continue to see a change in the health care delivery system with the dramatic shift in the population of elderly persons over the age of 65. This shift in the general population is resulting in an ongoing increase in the number of medical imaging procedures performed on elderly patients. Demographic and social effects of aging determine the way in which the elderly adapt to and view the process of aging. An individual's family size and perceptions of aging, economic resources, gender, race, ethnicity, social class, and the availability and delivery of health care will impact the quality of the aging experience. Biological age will be much more critical than chronological aging when determining the health status of the elderly. Healthier lifestyles and advancement in medical treatment will create a generation of successfully aging adults, which in turn should decrease the negative stereotyping of the elderly person. Attitudes of all health care professionals, whether positive or negative, will impact the care provided to the growing elderly population.

Education about the mental and physiological alterations associated with aging, along with the cultural, economical, and social influences accompanying aging, enables the radiographer to adapt imaging and therapeutic procedures to the elderly patient's disabilities resulting from age-related changes. The human body undergoes a multiplicity of physiological changes and failure in all organ systems. The aging experience is affected by heredity, lifestyle choices, physical health, and attitude, making it highly individualized. No one individual's aging process is predictable and is never exactly the same as that of any other individual. Radiologic technologists must use their knowledge, abilities, and skills to adjust imaging procedures to accommodate for disabilities and diseases encountered with geriatric patients. Safety and comfort of the patient is essential in maintaining compliance throughout imaging procedures. Implementation of skills such as communication, listening, sensitivity, and empathy all lead to patient compliance. The JCAHO, recognizing the importance of age-based communication competencies for the elderly, requires documentation of achievement of these skills by the employees of accredited health care organizations. Knowledge of age-related changes and disease processes will enhance the radiographer's ability to provide diagnostic information and treatment in providing care that meets the needs of the increasing elderly patient population.

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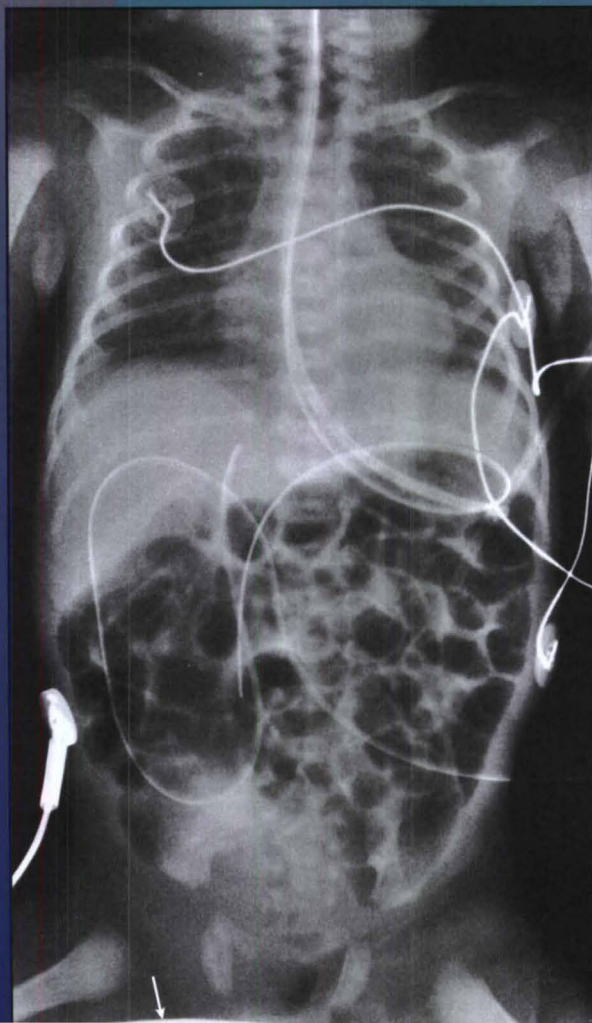


30

# MOBILE RADIOGRAPHY

KARI J. WETTERLIN

Mobile AP chest and abdomen radiograph of a neonate. The exposure technique demonstrates the anatomy of the entire chest and abdomen. Note the gonad shield accurately positioned on this male infant (*arrow*).



## OUTLINE

Principles of mobile radiography, 234  
Mobile x-ray machines, 234  
Technical considerations, 235  
Radiation safety, 238  
Isolation considerations, 239  
Performing mobile examinations, 240

## RADIOGRAPHY, 242

Chest, 242  
Abdomen, 246  
Pelvis, 250  
Femur, 252  
Cervical spine, 256  
Chest and abdomen: neonate, 258



## Principles of Mobile Radiography

*Mobile radiography* using transportable radiographic equipment allows imaging services to be brought to the patient. In contrast to the large stationary machines found in radiographic rooms, compact mobile radiography units can produce diagnostic images in virtually any location (Fig. 30-1). Mobile radiography is commonly performed in patient rooms, emergency rooms, intensive care units, surgery and recovery rooms, as well as nursery and neonatal units. Some machines are designed for transport by automobile or van to nursing homes, extended care facilities, or other off-site locations requiring radiographic imaging services.

Mobile radiography was first used by the military for treating battlefield injuries during World War I. Small portable units were designed to be carried by soldiers and set up in field locations. Although mobile equipment is no longer “carried” to the patient, the term portable has persisted and is often used in reference to mobile procedures.

This chapter focuses on the most common projections performed with mobile radiography machines. The basic principles of mobile radiography are detailed, and helpful hints are provided for successful completion of the examinations. An understanding of common projections enables the radiographer to perform most mobile examinations ordered by the physician.

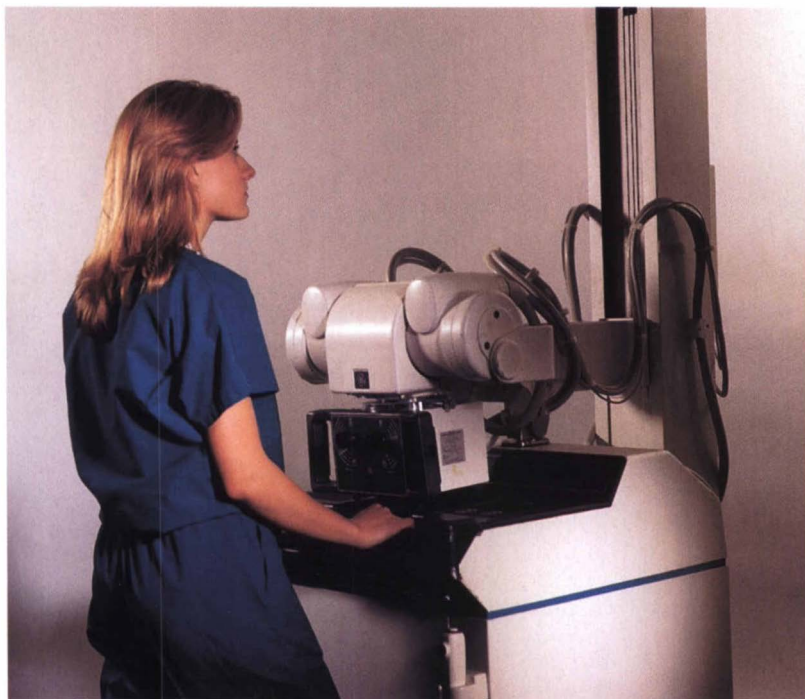
## Mobile X-Ray Machines

Mobile x-ray machines are not as sophisticated as the larger stationary machines in the radiology department. Although mobile units are capable of producing images of most body parts, they vary in their exposure controls and power sources (or generators).

A typical mobile x-ray machine has controls for setting kilovolt (peak) (kVp) and milliamperage-seconds (mAs). The mAs control automatically adjusts milliamperage (mA) and time to preset values. Maximum settings differ among manufacturers, but mAs typically range from 0.04 to 320 and kVp from 40 to 130. The total power of the unit varies between 15 and 25 kilowatts (kW), which is adequate for most mobile projections. By comparison, the power of a stationary radiography unit can reach 150 kW (150 kVp, 1000 mA) or more.

Some mobile x-ray machines have anatomic programming similar to stationary units. The anatomic programmer automatically sets all exposure factors to preset values based on the selected examination. The radiographer can adjust these settings as needed to compensate for differences in the size or condition of a patient. Automatic exposure control (AEC) may be available for some mobile machines. A paddle containing an ionization chamber is placed behind the IR and is used to determine the exposure time. However, with the increasing use of computed radiography (CR), anatomic programming and AEC may not be as useful. The much wider dynamic range available with CR and the ability to manipulate the final image with the computer result in images of proper density without the use of automatic systems.

Mobile x-ray machines are classified into two categories—*battery operated* and *capacitor discharge*—depending on the power source.



**Fig. 30-1** Radiographer driving a battery-operated mobile radiography machine to a patient's room.

## BATTERY-OPERATED MOBILE UNITS

Battery-operated machines use two different sets of batteries. One set, consisting of as many as 10 12-V lead acid batteries, controls the x-ray power output; the other set provides the power for the self-propelled driving ability. When the batteries are fully charged, these machines can be used for as many as 10 to 15 x-ray exposures and can be driven reasonable distances around the institution. Recharging after heavy use may be necessary to ensure maximum consistency in radiation output. The driving mechanisms include forward and reverse speeds; because of the power drive, a strong "deadman" type of brake is standard. A deadman brake stops the machine instantly when the push-handle is released. The advantages of these machines are that they are cordless and they provide constant kVp and mAs.

## CAPACITOR-DISCHARGE MOBILE UNITS

Capacitor-discharge mobile machines contain a capacitor-discharge unit and do not operate on batteries. A capacitor is a device that stores electrical energy. The radiation is generated when an electrical discharge is sent across the x-ray tube electrodes from a bank of high-voltage capacitors. The capacitor must be charged briefly before each exposure, with the power coming from a standard 110-V outlet. Larger capacitor-discharge machines may require a 220-V outlet. These machines are not self-propelling, and they are typically much lighter as a result of not having batteries. They are moved around the institution manually.

In a capacitor-discharge system, the kVp drops constantly during the length of the exposure. For example, the kVp may start at 100 and may drop to 80 by the end of an exposure. This drop may result in inadequate penetration of thick body areas. Consequently, special attention must be given to creating a technique chart that uses higher kVp and lower mAs than would normally be used with a conventional generator. If the desired technique normally requires 90 kVp at 20 mAs on noncapacitor discharge machines, using a technique of 100 kVp on a capacitor-discharge unit is preferred because the average kVp during the exposure is about 92. The advantages of capacitor-discharge machines are their smaller size and ease in movement. They also do not require long capacitor charging times before the exposure.

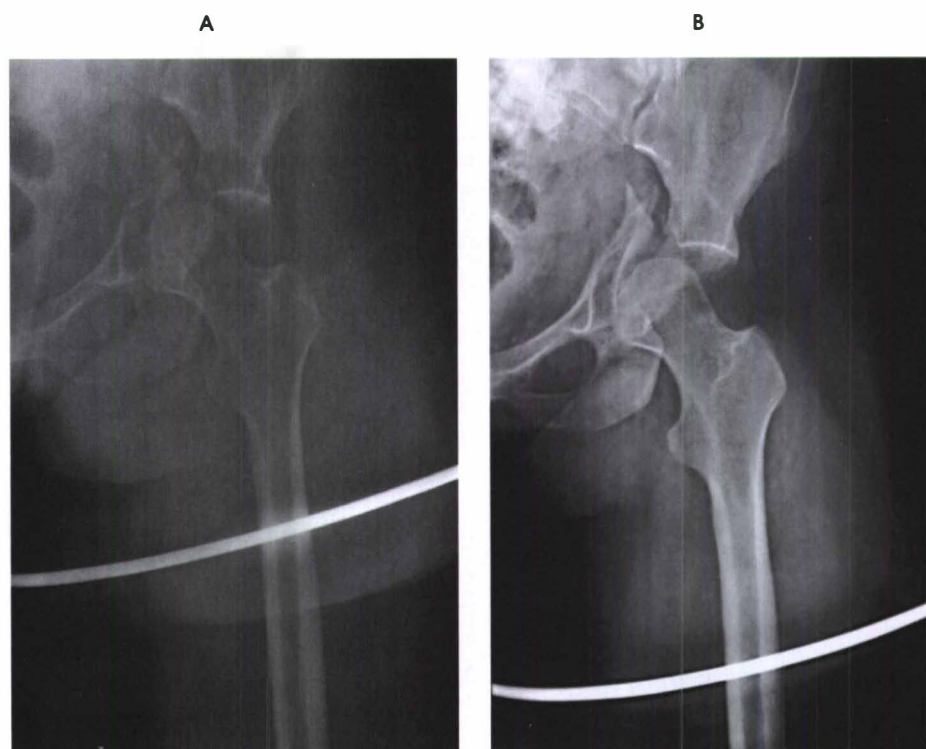
## Technical Considerations

Mobile radiography presents the radiographer with challenges different from those experienced in performing examinations with stationary equipment in the radiology department. Although the positioning of the patient and placement of the central ray are essentially the same, three important technical matters must be clearly understood to perform optimum mobile examinations: the *grid*, the *anode heel effect*, and the *source-to-image receptor distance (SID)*. In addition, exposure technique charts must be available (see Fig. 30-4).

## GRID

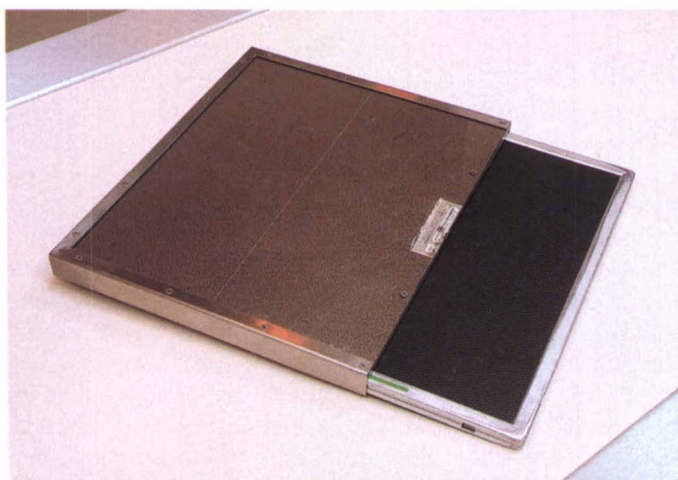
For optimum imaging, a *grid* must be level, centered to the central ray, and correctly used at the recommended focal distance, or radius. When a grid is placed on an unstable surface such as the mattress of a bed, the weight of the patient can cause the grid to tilt "off-level." If the grid tilts transversely, the central ray forms an angle across the long axis. Image density is lost as a result of grid "cutoff" (Fig. 30-2). If the grid tilts longitudinally, the central ray angles through the long axis. In this case, grid cutoff is avoided, but the image may be distorted or elongated.

A grid positioned under a patient can be difficult to center. If the central ray is directed to a point transversely off the midline of a grid more than 1 to 1½ inches (2.5 to 3.8 cm), a cutoff effect similar to that produced by an off-level grid results. The central ray can be centered longitudinally to any point along the midline of a grid without cutoff. Depending on the procedure, beam-restriction problems may occur. If this happens, a portion of the image is "collimated off," or patient exposure is excessive because of an oversized exposure field.



**Fig. 30-2** Mobile radiograph of a proximal femur and hip, demonstrating comminuted fracture of the left acetabulum. **A**, Poor-quality radiograph resulted when the grid was transversely tilted far enough to produce significant grid cutoff. **B**, Excellent-quality repeat radiograph on the same patient, performed with the grid accurately positioned perpendicular to the central ray.





**Fig. 30-3** Grid mounted on a rigid frame device and protected. Grid holder allows easy insertion of a IR for mobile radiography uses.

**TABLE 30-1**

Cathode placement for mobile projections\*

Part	Projection	Cathode placement
Chest	AP	Diaphragm
	AP—decubitus	Down side of chest
Abdomen	AP	Diaphragm
	AP—decubitus	Down side of abdomen
Pelvis	AP	Upper pelvis
Femur	AP	Proximal femur
	Lateral	Proximal femur
Cervical spine	Lateral	Over lower vertebrae (40-inch [102-cm] SID only)
Chest and abdomen in neonate	All	No designation†

AP, Anteroposterior; SID, source-to-image receptor distance.

\*The cathode side of the beam has the greatest intensity.

†Not necessary because of small field size of the collimator.

Grids used for mobile radiography are often of the focused type. However, many radiology departments continue to use the older, parallel-type grids for some or all mobile examinations. All focused grids have a recommended focal range, or radius, that varies with the grid ratio. Projections taken at distances greater or less than the recommended focal range can produce cutoff in which image density is reduced on lateral margins. Grids with a lower ratio have a greater focal range, but they are less efficient for cleaning up scatter radiation. The radiographer must be aware of the *exact* focal range for the grid used. Most focused grids used for mobile radiography have a ratio of 6:1 or 8:1, and they have a focal range of about 36 to 44 inches (91 to 112 cm). This focal range allows mobile examinations to be performed efficiently. Inverting a focused grid causes a pronounced cutoff effect similar to that produced by improper distance.

Today most grids are mounted on a protective frame, and the IR is easily inserted behind the grid (Fig. 30-3). A final concern regarding grids relates to the use of “tape-on” grids. If a grid is not mounted on a IR holder frame but instead is manually fastened to the surface of the IR with tape, care must be taken to ensure that the tube side of the grid faces the x-ray tube. The examinations described in this chapter present methods of ensuring proper grid IR placement for projections that require a grid.

### ANODE HEEL EFFECT

Another consideration in mobile radiography is the *anode heel effect*. The heel effect causes a decrease of image density under the anode side of the x-ray tube. The heel effect is more pronounced with the following:

- Short SID
- Larger field sizes
- Small anode angles



Short SIDs and large field sizes are common in mobile radiography. Furthermore, in mobile radiography, the radiographer has control of the anode-cathode axis of the x-ray tube relative to the body part. Therefore correct placement of the anode-cathode axis with regard to the anatomy is essential. When performing a mobile examination, the radiographer may not always be able to orient the anode-cathode axis of the tube to the desired position because of limited space and maneuverability in the room. For optimum mobile radiography, the anode and cathode sides of the x-ray tube should be clearly marked to indicate where the high-tension cables enter the x-ray tube, and the radiographer should use the heel effect maximally (Table 30-1).

### SOURCE-TO-IMAGE RECEPTOR DISTANCE

The SID should be maintained at 40 inches (102 cm) for most mobile examinations. A standardized distance for all patients and projections helps to ensure consistency in imaging. Longer SIDs—40 to 48 inches (102 to 122 cm)—require increased mAs to compensate for the additional distance. The mA limitations of a mobile unit necessitate longer exposure times when the SID exceeds 40 inches (102 cm). Despite the longer exposure time, a radiograph with motion artifacts may result if the SID is greater than 40 inches (102 cm). In addition, motion artifacts may occur in the radiographs of critically ill adult patients and infants or small children who require chest and abdominal examinations but may not be able to hold their breath.

### RADIOGRAPHIC TECHNIQUE CHARTS

A radiographic technique chart should be available for use with every mobile machine. The chart should display, in an organized manner, the standardized technical factors for all the radiographic projections done with the machine (Fig. 30-4). A caliper should also be available; this device is used to measure the thickness of body parts to ensure that accurate and consistent exposure factors are used. Measuring the patient also allows the radiographer to determine the optimum kVp level for all exposures (Fig. 30-5).

MOBILE RADIOGRAPHIC TECHNIQUE CHART					
AMX—4    40-inch SID    Lanex medium screens/TML    8:1 grid					
Part	Projection	Position	cm—kVp	mAs	Grid
Chest	AP	Supine/upright	21—85	1.25	No
	AP	Lateral decubitus	21—85	6.25	Yes
Abdomen	AP	Supine	23—74	25	Yes
	AP	Lateral decubitus	23—74	32	Yes
Pelvis	AP	Supine	23—74	32	Yes
Femur (distal)	AP	Supine	15—70	10	Yes
	Lateral	Dorsal decubitus	15—70	10	Yes
C-spine	Lateral	Dorsal decubitus	10—62	20	Yes
NEONATAL					
Chest/abdomen	AP	Supine	7—64	0.8	No
	Lateral	Dorsal decubitus	10—72	1	No

**Fig. 30-4** Sample radiographic technique chart showing the manual technical factors used for the 10 common mobile projections described in this chapter. The kVp and mAs factors are for the specific centimeter measurements indicated. Factors vary depending on the actual centimeter measurement.



**Fig. 30-5** Radiographer measuring the thickest portion of the femur to determine exact technical factors needed for the examination.

## Radiation Safety

Radiation protection for the radiographer, others in the immediate area, and the patient is of paramount importance when mobile examinations are performed. *Mobile radiography produces some of the highest occupational radiation exposures for radiographers.* The radiographer should wear a lead apron and should stand as far away from the patient, x-ray tube, and useful beam as the room and the exposure cable allow. The recommended *minimal* distance is 6 feet (2 m). For a horizontal (cross-table) x-ray beam, or for an upright AP chest projection, the radiographer should stand at a right angle (90 degrees) to the primary beam and the object being radiographed. The least amount of scatter radiation occurs at this position (Fig. 30-6). However, shielding and distance have a greater effect on exposure reduction and therefore should always be considered first.

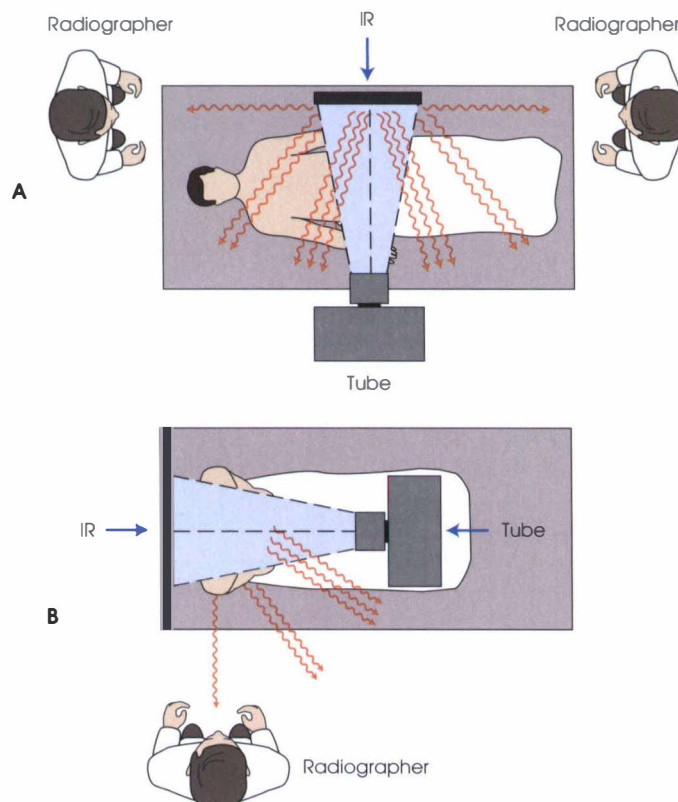
The single most effective means of radiation protection is *distance*. The radiographer should inform all persons in the immediate area that an x-ray exposure is about to occur so that they may leave to avoid exposure. Lead protection should be provided for any individuals who are unable to leave the room and for those who may have to hold a patient or IR.

The patient's gonads should be shielded with appropriate radiation protection devices for any of the following situations:

- X-ray examinations performed on children
- X-ray examinations performed on patients of reproductive age
- Any examination for which the patient requests protection
- Examinations in which the gonads lie in or near the useful beam
- Examinations in which shielding will not interfere with imaging of the anatomy that must be demonstrated (Fig. 30-7)

In addition, the source-to-skin distance (SSD) cannot be less than 12 inches (30 cm), in accordance with federal safety regulations.<sup>1</sup>

<sup>1</sup>National Council on Radiation Protection: *Report 102: Medical x-ray, electron beam and gamma ray protection for energies up to 50 MeV*, Bethesda, Md, 1989.



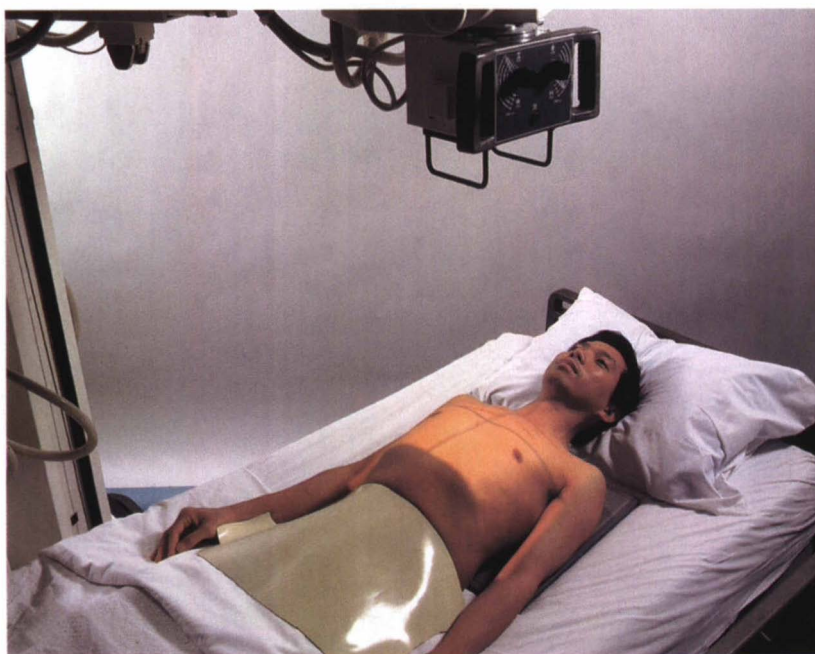
**Fig. 30-6** Whenever possible, the radiographer should stand at least 6 feet (2 m) from the patient and useful beam. The lowest amount of scatter radiation occurs at a right angle (90 degrees) from the primary x-ray beam. **A**, Note radiographer standing at either the head or foot of the patient at a right angle to the x-ray beam for a dorsal decubitus position lateral projection of the abdomen. **B**, Radiographer standing a right angle to the x-ray beam for an AP projection of the chest.

## Isolation Considerations

Two types of patients are often cared for in isolation units: (1) patients who have infectious microorganisms that could be spread to health care workers and visitors and (2) patients who need protection from potentially lethal microorganisms that may be carried by health care workers and visitors. Optimally, a radiographer entering an isolation room should have a full knowledge of the patient's disease, the way it is transmitted, and the proper way to clean and disinfect equipment before and after use in the isolation unit. However, because of the confidentiality of patient records, the radiographer may not be able to obtain information about a patient's specific disease. Therefore all patients must be treated with universal precautions. If isolation is used to protect the patient from receiving microorganisms (reverse isolation), a different protocol may be required. Institutional policy regarding isolation procedures should be available and strictly followed.

When performing mobile procedures in an isolation unit, the radiographer should wear the required protective apparel for the specific situation—gown, cap, mask, shoe covers, and gloves. All of this apparel is not needed for every isolation patient. For example, all persons entering a strict isolation unit wear a mask, a gown, and gloves, but only gloves are worn for drainage secretion precautions. The radiographer should always wash their hands with warm, soapy water before putting on gloves. The x-ray machine is taken into the room and moved into position. The IR is placed into a clean, protective cover. Pillowcases will not protect the IR or the patient if bodily fluids soak through them. A clean, impermeable cover should be used in situations in which bodily fluids may come into contact with the IR. For examinations of patients in strict isolation, two radiographers may be required to maintain a safe barrier (see Chapter 1).

After finishing the examination, the radiographer should remove and dispose of the mask, cap, gown, shoe covers, and the gloves according to institutional policies. All equipment that touched the patient or the patient's bed must be wiped with a disinfectant according to appropriate aseptic technique. The radiographer should wear new gloves, if necessary, while cleaning equipment. Hand washing is repeated before the radiographer leaves the room.



**Fig. 30-7** Patient ready for a mobile chest examination. Note lead shield placed over the patient's pelvis. This shield does not interfere with the examination.



## Performing Mobile Examinations

### INITIAL PROCEDURES

The radiographer should plan for the trip out of the radiology department. Ensuring that all of the necessary devices (IR, grid, tape, measuring caliper, markers, blocks, etc.) are transported with the mobile x-ray machine provides greater efficiency in performing examinations. Many mobile x-ray machines are equipped with a storage area for transporting IRs and supplies. If a battery-operated machine is used, the radiographer should check the machine to ensure that it is charged properly. An inadequately charged machine can interfere with performance and affect the quality of the radiograph.

Before entering the patient's room with the machine, the radiographer should follow several important steps (Box 30-1). The radiographer begins by checking that the correct patient is going to be examined. After confirming the identity of the patient, the radiographer enters, makes an introduction as a radiographer, and informs the patient about the x-ray examinations to be performed. While in the room, the radiographer observes any medical appliances, such as chest tube boxes, catheter bags, and IV poles, that may be positioned next to or hanging on the sides of the patient's bed. The radiographer should ask family members or visitors to step out of the room until the examination is finished. If necessary, the nursing staff should be alerted that assistance is required.

Communication and cooperation between the radiographer and nursing staff members are essential for proper patient care during mobile radiography. In addition, communication with the patient is *imperative*, even if the patient is or appears to be unconscious or unresponsive.

### THE EXAMINATION

Chairs, stands, IV poles, wastebaskets, and other obstacles should be moved from the path of the mobile machine. Lighting should be adjusted if necessary. If the patient is to be examined in the supine position, the base of the mobile machine should be positioned toward the middle of the bed. If a seated patient position is used, the base of the machine should be toward the foot of the bed.

For lateral and decubitus radiographs, positioning the base of the mobile machine parallel to or directly perpendicular to the bed allows the greatest ease in positioning the x-ray tube. Room size can also influence the base position used.

At times, the radiographer may have difficulty accurately aligning the x-ray tube parallel to the IR while standing at the side of the bed. When positioning the tube above the patient, the radiographer may need to check the x-ray tube and IR alignment from the foot of the bed to ensure that the tube is not tilted.

For all projections, the primary x-ray beam must be collimated no larger than the size of the IR. When the central ray is correctly centered to the IR, the light field coincides with or fits within the borders of the IR.

A routine and consistent system for labeling and separating exposed and unexposed IRs should be developed and maintained. It is easy to "double expose" IRs during mobile radiography, particularly if many examinations are performed at one time. Most institutions require additional identification markers for mobile examinations. Typically the time of examination (especially for chest radiographs) and technical notes such as the position of the patient are indicated. A log may be maintained for each patient and kept in the patient's room. The log should contain the exposure factors used for the projections and other notes regarding the performance of the examination.

### PATIENT CONSIDERATIONS

Patients requiring mobile radiography often are in extended care facilities or are immobile and among the most sick. They may be awake and lying in bed in traction because of a broken limb, or they may be critically ill and unconscious. A brief but total assessment of the patient must be conducted both before and during the examination. Some specific considerations to keep in mind are described in the following sections.

#### Assessment of the patient's condition

A thorough assessment of the patient's condition and room allows the radiographer to make necessary adaptations to ensure the best possible patient care and imaging outcome. The radiographer assesses the patient's level of alertness and respiration and then determines the extent to which the patient is able to cooperate and the limitations that may affect the procedure. Some patients may have varying degrees of drowsiness because of their medications or medical condition. Many mobile examinations are performed in patient's rooms immediately after surgery; these patients may be under the influence of various anesthetics.

#### BOX 30-1

Preliminary steps for the radiographer before mobile radiography is performed

- Announce your presence to the nursing staff, and ask for assistance if needed.
- Determine that the correct patient is in the room.
- Introduce yourself to patient and family as a radiographer and explain the examination.
- Observe the medical equipment in the room, as well as other apparatus and IV poles with fluids. Move the equipment if necessary.
- Ask family members and visitors to leave.\*

\*A family member may need to be present for the examination of a small child.

### Patient mobility

The radiographer must never move a patient or part of the patient's body without assessing the patient's ability to move or tolerate movement. At all times, *gentleness* and *caution* must prevail. If unsure, the radiographer should always check with the nursing staff or physician. For example, many patients who undergo total joint replacement may not be able to move the affected joint for a number of days or weeks. However, this may not be evident to the radiographer. Some patients may be able to indicate verbally their ability to move or their tolerance for movement. *The radiographer should never move a limb that has been operated on or is broken unless the nurse, the physician, or sometimes the patient grants permission.* Inappropriate movement of the patient by the radiographer during the examination may harm the patient.

### Fractures

Patients can have a variety of fractures and fracture types, ranging from one simple fracture to multiple fractures of many bones. A patient lying awake in a traction bed with a simple femur fracture may be able to assist with a radiographic examination. However, another patient may be unconscious and have multiple broken ribs, spinal fractures, or a severe closed head injury.

Few patients with multiple fractures are able to move or tolerate movement. The radiographer must be cautious, resourceful, and work in accordance with the patient's condition and pain tolerance. If a patient's trunk or limb must be raised into position for a projection, the radiographer should have ample assistance so that the part can be raised safely without causing harm or intense pain.

### Interfering devices

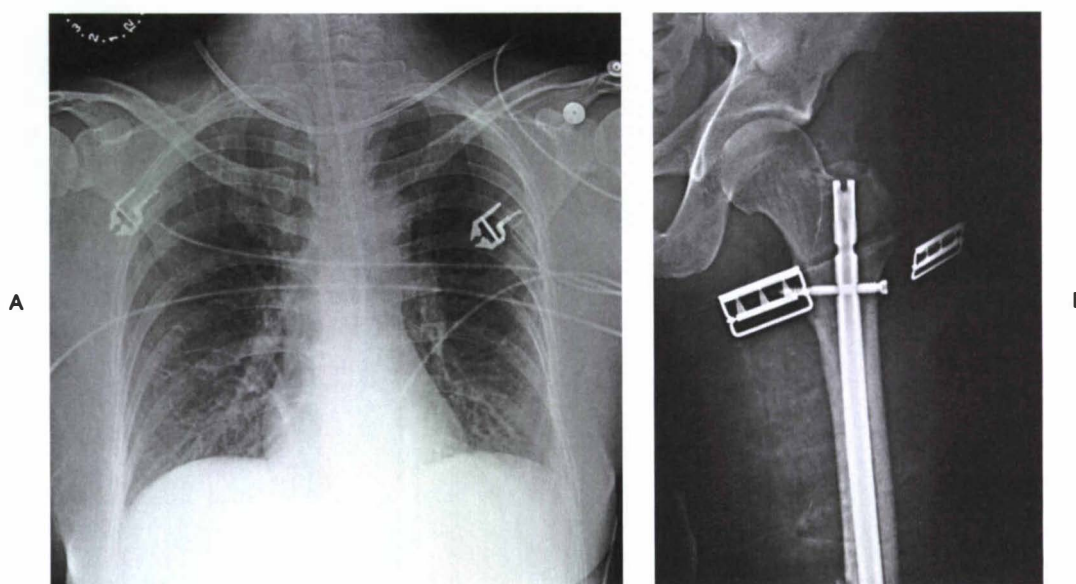
Patients who are in intensive care units or orthopedic beds because of fractures may be attached to a variety of devices, wires, and tubing. These objects may be in the direct path of the x-ray beam and consequently produce artifacts on the image. Experienced radiographers know which of these objects can be moved out of the x-ray beam. When devices such as fracture frames cannot be moved, it may be necessary to angle the central ray or adjust the IR to obtain the best radiograph possible. In many instances the objects have to be radiographed along with the body part (Fig. 30-8). The radiographer must exercise caution when handling any of these devices and should never remove traction devices without the assistance of a physician.

### Positioning and asepsis

During positioning, the IR (with or without a grid) often is perceived by the patient as cold, hard, and uncomfortable. Therefore before the IR is put in place, the patient should be warned of possible discomfort and assured that the examination will be for as short a time as possible. The patient will appreciate the radiographer's concern and efficiency in completing the examination as quickly as possible.

If the surface of the IR touches bare skin, it can stick, making positioning adjustments difficult. *The skin of older patients may be thin and dry and can be torn by manipulation of the IR if care is not taken.* A cloth or paper cover over the IR can protect the patient's skin and alleviate some of the discomfort by making it feel less cold. The cover also helps to keep the IR clean. IRs that contact the patient directly should be wiped off with a disinfectant for asepsis and infection control.

The IR must be enclosed in an appropriate, impermeable barrier in any situation in which it may come in contact with blood, body fluids, and other potentially infectious material. A contaminated IR can be difficult and sometimes impossible to clean. Approved procedures for disposing of used barrier must be followed.



**Fig. 30-8** **A**, Mobile radiograph of the chest. Note the variety of objects in the image that could not be removed for the exposure. **B**, Mobile radiograph of proximal femur and hip. Metal buckles could not be removed for the exposure.



### ▲ AP PROJECTION\*

#### Upright or supine

**Image receptor:** 35 × 43 cm lengthwise or crosswise, depending on body habitus; a non-grid or grid IR can be used, depending on patient size or institutional policy

#### Position of patient

Depending on the condition of the patient, elevate the head of the bed to a semierect or sitting position. The projection should be performed with the patient in the upright position or to the greatest angle tolerated by the patient whenever possible. Use the supine position for critically ill or injured patients.

\*The nonmobile projection is described in Chapter 10.

#### Position of part

Center the midsagittal plane to the IR.

- To include the entire chest, position the IR under the patient with the top about 2 inches (5 cm) above the *relaxed* shoulders. The exact distance depends on the size of the patient. When the patient is supine, the shoulders may move to a higher position relative to the lungs. Adjust accordingly.
- Be certain that the patient's shoulders are relaxed; then internally rotate the patient's arms to prevent scapular superimposition of the lung field, if not contraindicated.
- Ensure that the patient's upper torso is not rotated or leaning toward one side (Fig. 30-9).
- *Shield gonads.*
- *Respiration:* Inspiration, unless otherwise requested. If the patient is receiving respiratory assistance, carefully watch the patient's chest to determine the inspiratory phase for the exposure.

#### Central ray

- Perpendicular to the long axis of the sternum and the center of the IR. The central ray should enter about 3 inches (7.6 cm) below the jugular notch at the level of T7

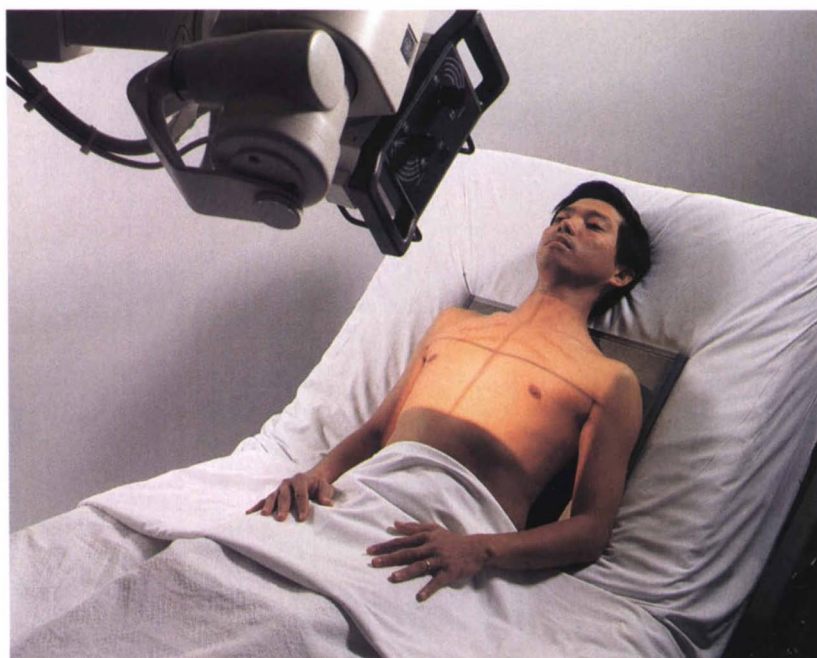


Fig. 30-9 Mobile AP chest: partially upright.



## COMPUTED RADIOGRAPHY



A grid must be used for all mobile computed radiography chest examinations if the exposure technique is more than 90 kVp. (Review the manufacturer's protocol for the exact kVp levels for the unit that is used.) When a crosswise-positioned grid is used, the central ray must be perpendicular to the grid to prevent grid cutoff.

## Structures shown

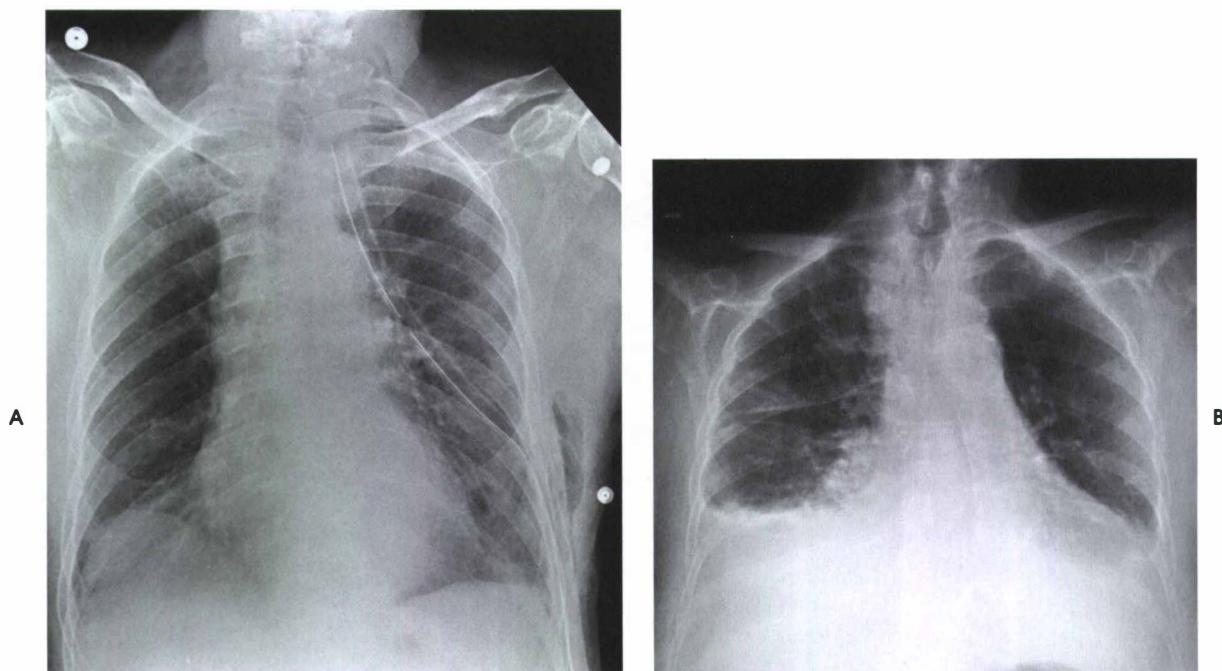
This projection demonstrates the anatomy of the thorax, including the heart, trachea, diaphragmatic domes, and most importantly the entire lung fields, including vascular markings (Fig. 30-10).

## EVALUATION CRITERIA

The following should be clearly demonstrated:

- No motion. Well defined (not blurred) diaphragmatic domes and lung fields
- Lung fields in their entirety, including costophrenic angles
- Pleural markings
- Ribs and thoracic intervertebral disk spaces faintly visible through heart shadow
- No rotation with medial portion of clavicles and lateral border of ribs equidistant from vertebral column

**NOTE:** To ensure the proper angle from the x-ray tube to the IR, the radiographer can double-check the shadow of the shoulders from the field light projected onto the IR. If the shadow of the shoulders is thrown far above the upper edge of the IR, the angle of the tube must be corrected.



**Fig. 30-10** Mobile AP chest radiographs in critically ill patients. **A**, Patient with postoperative left thoracotomy and chest tube, infiltrate or atelectasis in the left base, segmental elevation of the right hemidiaphragm, and soft tissue emphysema on the left. **B**, Patient with small left pleural effusion and moderate right effusion, cardiomegaly, mild pulmonary vascular congestion, and calcification and torsion of the aorta.



## AP OR PA PROJECTION\*

### Right or left lateral decubitus position

**Image receptor:** 35 × 43 cm lengthwise; a non-grid or grid IR can be used, depending on patient size

#### Position of patient

- Place the patient in the lateral recumbent position.
- Flex the patient's knees to provide stabilization, if possible.
- Place a firm support under the patient to elevate the body 2 to 3 inches (5 to 8 cm) and prevent the patient from sinking into the mattress.
- Raise both of the patient's arms up and away from the chest region, preferably above the head. An arm lying on the patient's side can imitate a region of free air.
- Ensure that the patient cannot roll out of bed.

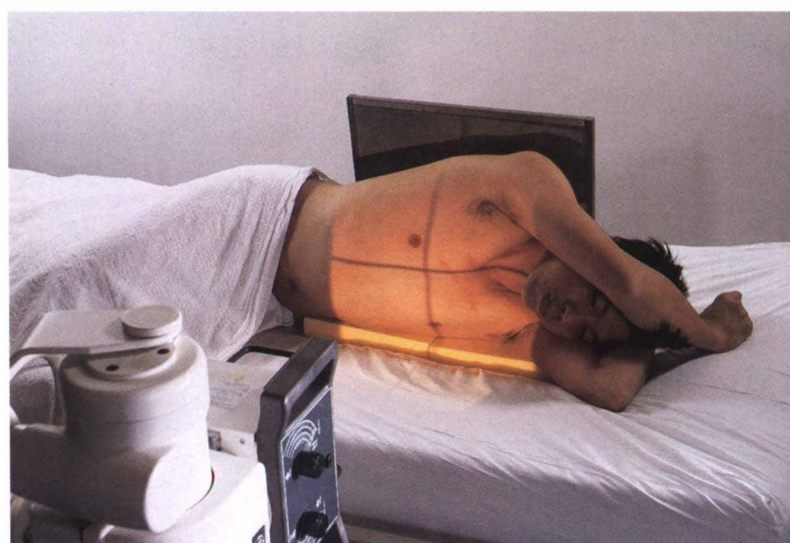
#### Position of part

- Position the patient for the AP projection whenever possible. It is much easier to position an ill patient (particularly the arms) for an AP.
- Adjust the patient to ensure a lateral position. The coronal plane passing through the shoulders and hips should be vertical.
- Place the IR behind the patient and below the support so that the lower margin of the chest will be visualized.
- Adjust the grid so that it extends approximately 2 inches (5 cm) above the shoulders. The IR should be supported in position and not leaning against the patient to avoid distortion (Fig. 30-11).
- *Shield gonads.*
- *Respiration:* Inspiration unless otherwise requested.

#### Central ray

- Horizontal and perpendicular to the center of the IR, entering the patient at a level of 3 inches (7.6 cm) below the jugular notch

\*The nonmobile projection is described in Chapter 10.



**Fig. 30-11** Mobile AP chest: left lateral decubitus position. Note yellow block placed under the chest to elevate it. The block is necessary to ensure that the left side of the chest is included on the image.

**Structures shown**

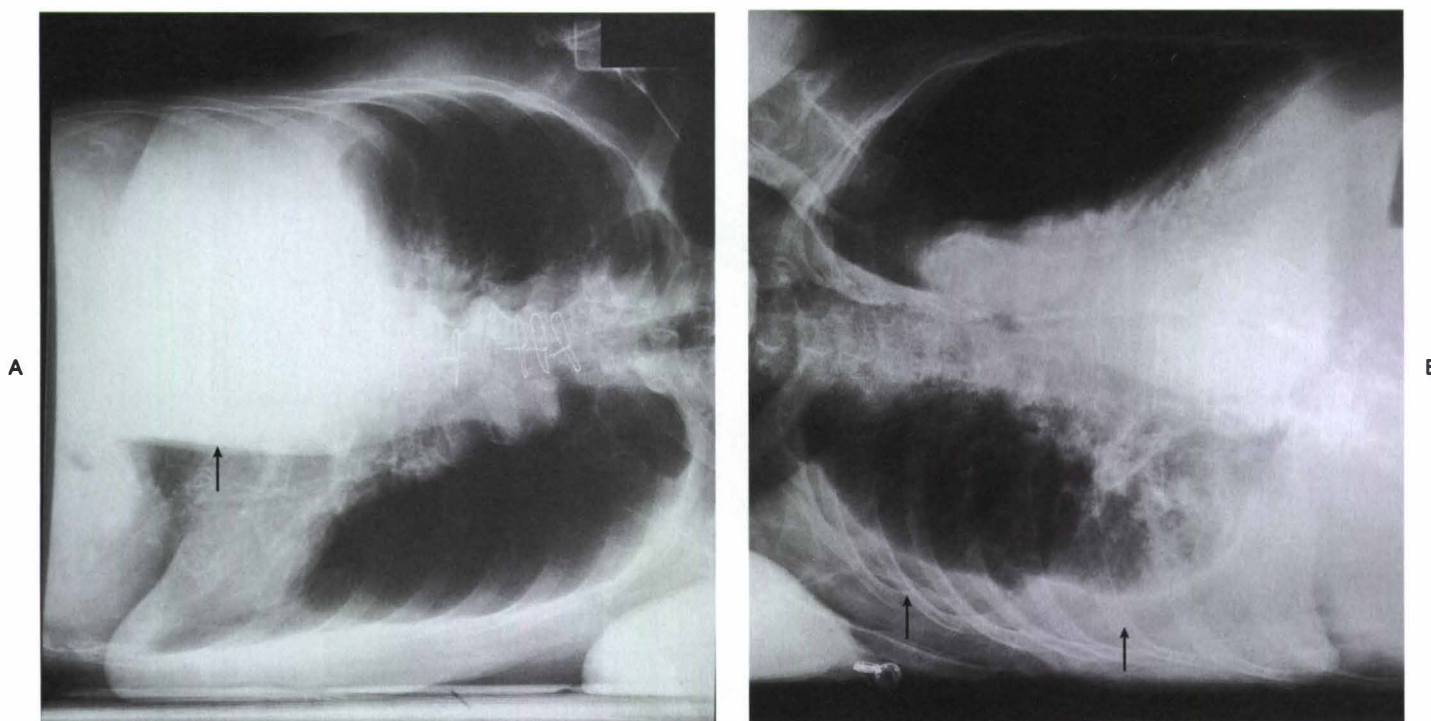
This projection demonstrates the anatomy of the thorax, including the entire lung fields and any air or fluid levels that may be present (Fig. 30-12).

**EVALUATION CRITERIA**

The following should be clearly demonstrated:

- No motion
- No rotation
- Affected side in its entirety (upper lung for free air and lower lung for fluid)
- Patient's arms out of region of interest
- Proper identification to indicate that decubitus position was used

**NOTE:** Fluid levels in the pleural cavity are best visualized with the affected side down, which also prevents mediastinal overlapping. Air levels are best visualized with the unaffected side down. The patient should be in position for at least 5 minutes before the exposure is made to allow air to rise and fluid levels to settle.



**Fig. 30-12** Mobile AP chest radiographs performed in lateral decubitus positions in critically ill patients. **A**, Left lateral decubitus position. The patient has a large right pleural effusion (*arrow*) and no left effusion. Note that the complete left side of thorax is visualized because of elevation on a block. **B**, Right lateral decubitus position. The patient has right pleural effusion (*arrows*), cardiomegaly, and mild pulmonary vascular congestion. Note that the complete right side of thorax is visualized because of elevation on a block.



### AP PROJECTION\*

**Image receptor:** 35 × 43 cm  
lengthwise grid

#### Position of patient

- If necessary, adjust the patient's bed to achieve a horizontal bed position.
- Place the patient in a supine position.

\*The nonmobile projection is described in Chapter 16.

#### Position of part

- Position the grid under the patient to demonstrate the abdominal anatomy from the pubic symphysis to the upper abdominal region.
- Keep the grid from tipping side to side by placing it in the center of the bed and stabilizing it with blankets or towels if necessary.
- Use the patient's draw sheet to roll the patient; this makes it easier to shift the patient from side to side during positioning of the IR, and it provides a barrier between the patient's skin and the grid.
- Center the midsagittal plane of the patient to the midline of the grid.
- Center the grid to the level of the iliac crests. If the emphasis is on the upper abdomen, center the grid 2 inches (5 cm) above the iliac crests or high enough to include the diaphragm.
- Adjust the patient's shoulders and pelvis to lie in the same plane (Fig. 30-13).
- Move the patient's arms out of the region of the abdomen.
- *Shield gonads.* Note that this may not be possible in a female patient.
- *Respiration:* Expiration.

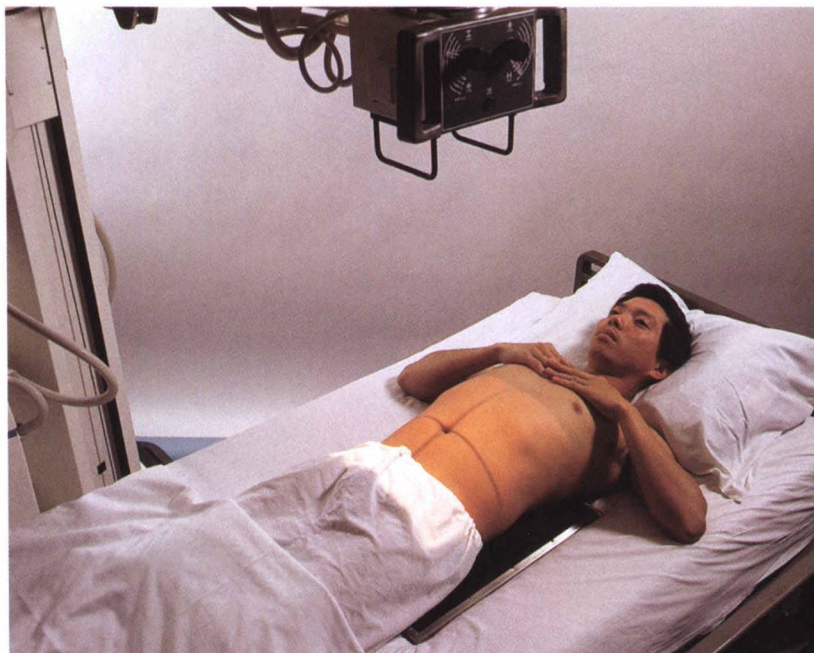


Fig. 30-13 Mobile AP abdomen.

## Central ray

- Perpendicular to the center of the grid along the midsagittal plane and at the level of the iliac crests or the tenth rib laterally

## Structures shown

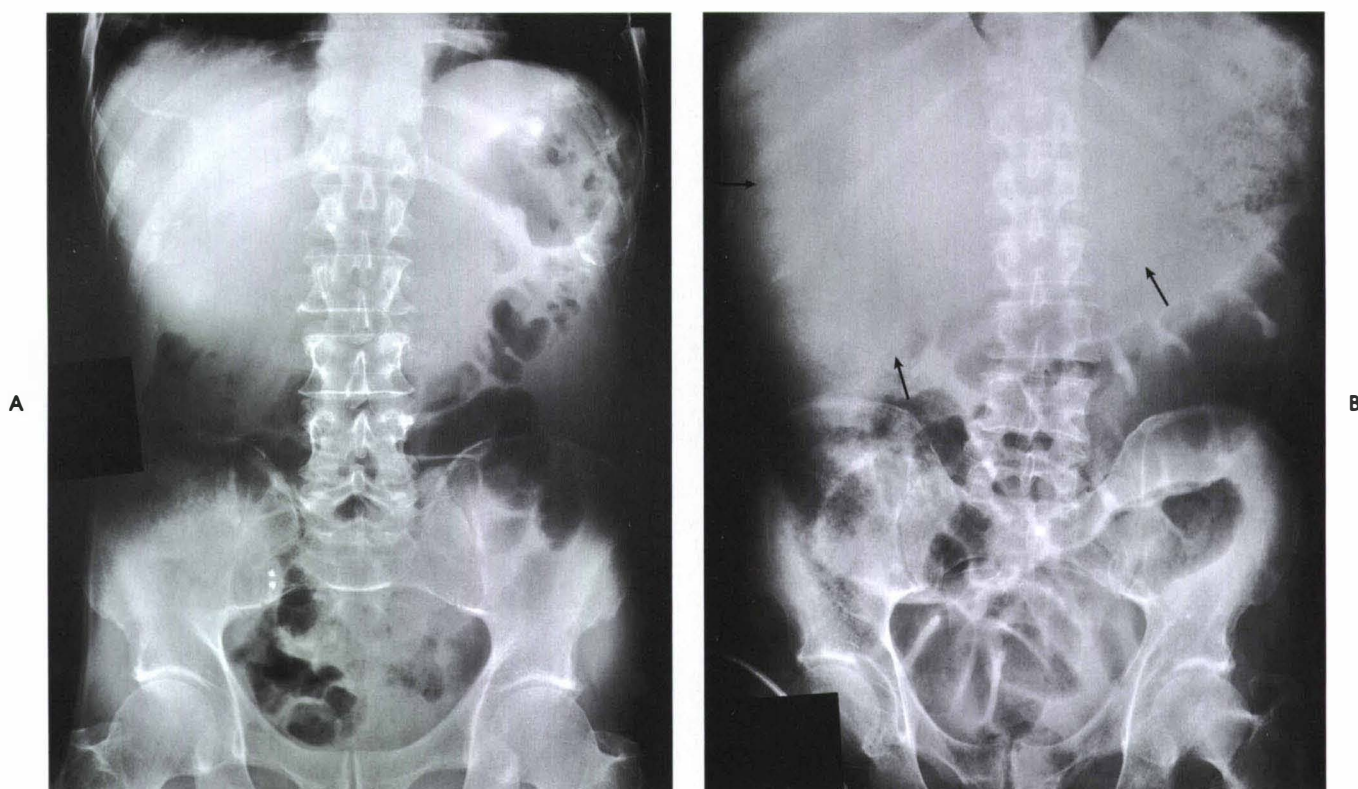
This projection demonstrates the following: the inferior margin of the liver; the spleen, kidneys, and psoas muscles; calcifications; and evidence of tumor masses. If the image includes the upper abdomen and diaphragm, the size and shape of the liver may be seen (Fig. 30-14).

## EVALUATION CRITERIA

The following should be clearly demonstrated:

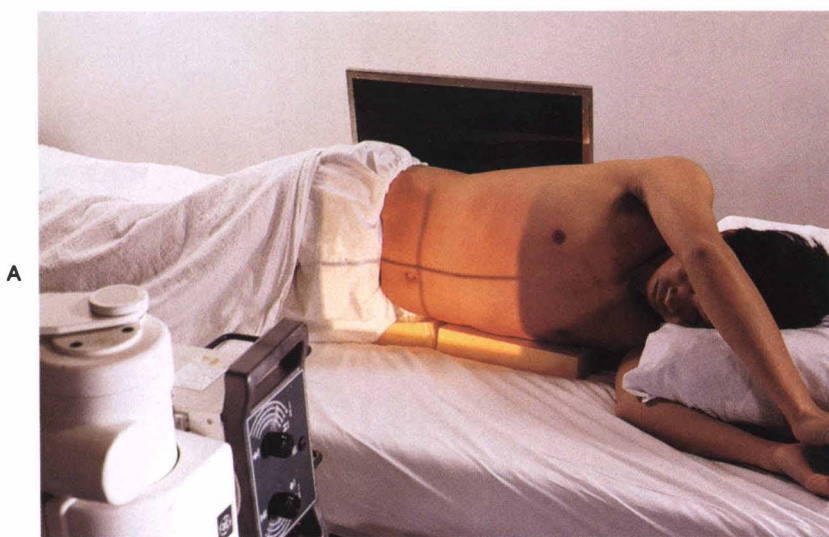
- No motion
- Outlines of the abdominal viscera
- Abdominal region, including pubic symphysis or diaphragm (both may be seen on some patients)
- Vertebral column in center of image
- Psoas muscles, lower margin of liver, and kidney margins
- No rotation
- Symmetric appearance of vertebral column and iliac wings

**NOTE:** Hypersthenic patients may require two separate projections using a crosswise grid. One grid is positioned for the upper abdomen and the other for the lower abdomen.



**Fig. 30-14** Mobile AP abdomen radiographs. **A**, Abdomen without pathology. Note that the entire abdomen is seen in this patient. **B**, Patient with hepatomegaly encompassing the entire upper abdomen (arrows). Note that the diaphragm cannot be seen in this patient, who has a longer abdomen than the patient in **A**.





**Fig. 30-15** Mobile AP abdomen radiograph: left lateral decubitus position. **A**, AP projection. **B**, PA projection. Note yellow blocks placed under the abdomen to level the abdomen and keep the patient from sinking into the mattress.



## AP OR PA PROJECTION\*

### Left lateral decubitus position

**Image receptor:** 35 × 43 cm  
lengthwise grid

#### Position of patient

- Place the patient in the left lateral recumbent position unless requested otherwise.
- Flex the patient's knees slightly to provide stabilization.
- If necessary, place a firm support under the patient to elevate the body and keep the patient from sinking into the mattress.
- Raise both of the patient's arms away from the abdominal region, if possible. The right arm lying on the side of the abdomen may imitate a region of free air.
- Ensure that the patient cannot fall out of bed.

#### Position of part

- Use the PA or AP projection, depending on the room layout.
- Adjust the patient to ensure a true lateral position. The coronal plane passing through the shoulders and hips should be vertical.
- Place the grid vertically in front of the patient for a PA projection and behind the patient for an AP projection. The grid should be supported in position and not leaned against the patient; this position prevents grid cutoff.
- Position the grid so that its center is 2 inches (5 cm) above the iliac crests to ensure that the diaphragm is included. The pubic symphysis and lower abdomen do not have to be visualized (Fig. 30-15).
- Before making the exposure, be certain that the patient has been in the lateral recumbent position for at least 5 minutes to allow air to rise and fluid levels to settle.
- *Shield gonads.*
- *Respiration:* Expiration.

\*The nonmobile projection is described in Chapter 16.



## Central ray

- Horizontal and perpendicular to the center of the grid, entering the patient along the midsagittal plane

## Structures shown

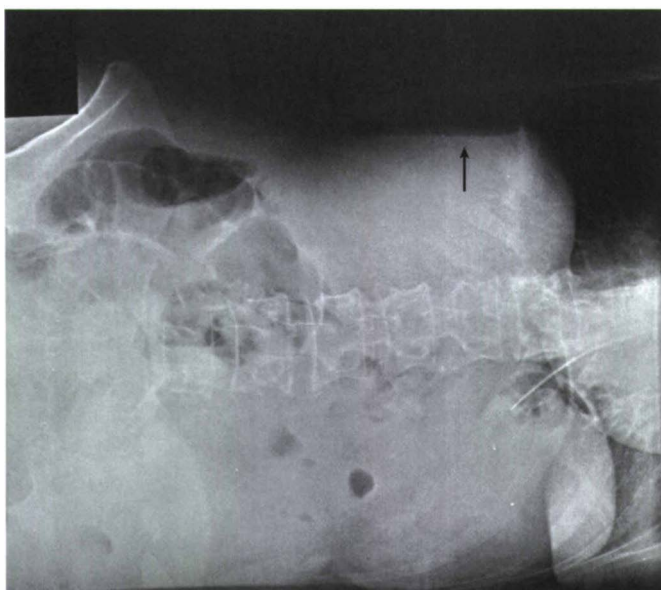
Air or fluid levels within the abdominal cavity are demonstrated. These projections are especially helpful in assessing free air in the abdomen. The right border of the abdominal region must be visualized (Figs. 30-16).

## EVALUATION CRITERIA

The following should be clearly demonstrated:

- No motion
- Well-defined diaphragm and abdominal viscera
- Air or fluid levels, if present
- Right and left abdominal wall and flank structures
- No rotation
- Symmetric appearance of vertebral column and iliac wings

**NOTE:** Hypersthenic patients may require two projections with the 35 × 43 cm grid positioned crosswise to visualize the entire abdominal area. A patient with a long torso may require two projections with the grid lengthwise to visualize the entire abdominal region.



**Fig. 30-16** Mobile AP abdomen radiograph: left lateral decubitus position. Free intraperitoneal air is seen on the upper or right side of the abdomen (*arrow*). The radiograph is slightly underexposed to demonstrate the free air more easily.

## AP PROJECTION\*

**Image receptor:** 35 × 43 cm grid crosswise

### Position of patient

- Adjust the patient's bed horizontally so that the patient is in a supine patient position.
- Move the patient's arms out of the region of the pelvis.

\*The nonmobile projection is described in Chapter 7.

### Position of part

- Position the grid under the pelvis so that the center is midway between the anterior superior iliac spine (ASIS) and the pubic symphysis. This is about 2 inches (5 cm) inferior to the ASIS and 2 inches (5 cm) superior to the pubic symphysis.
- Center the midsagittal plane of the patient to the midline of the grid. The pelvis should not be rotated.
- Rotate the patient's legs medially approximately 15 degrees when not contraindicated (Fig. 30-17).
- *Shield gonads:* Note that this may not be possible in female patients.
- *Respiration:* Suspend.



**Fig. 30-17** Mobile AP pelvis. Note that the grid is placed horizontal and perpendicular to the central ray.

## Central ray

- Perpendicular to the midpoint of the grid, entering the midsagittal plane. The central ray should enter the patient 2 inches (5 cm) above the pubic symphysis and 2 inches (5 cm) below the ASIS.

## Structures shown

This projection demonstrates the pelvis, including the following: both hip bones; the sacrum and coccyx; and the head, neck, trochanters, and proximal portion of the femurs (Fig. 30-18).

## EVALUATION CRITERIA

The following should be clearly demonstrated:

- Entire pelvis, including proximal femurs and both hip bones
- No rotation
- Symmetric appearance of iliac wings and obturator foramina
- Both greater trochanters and ilia equidistant from edge of radiograph
- Femoral necks not foreshortened and greater trochanters in profile

**NOTE:** It is not uncommon for the weight of the patient to cause the bottom edge of the grid to tilt upward. The x-ray tube may need to be angled caudally to compensate and maintain proper grid alignment, thereby preventing grid cutoff. However, the exact angle needed is not always known or easy to determine. The radiographer may want to lower the foot of the bed slightly (Fowler's position), thereby shifting the patient's weight more evenly on the grid and allowing it to be flat. A rolled-up towel or blanket placed under the grid also may be useful to prevent lateral tilting. If the bed is equipped with an inflatable air mattress, the maximum inflate mode is recommended. Tilting the bottom edge of the grid downward is another possibility. Check the level of the grid carefully and compensate accordingly.



**Fig. 30-18** Mobile AP pelvis radiograph. This patient has a comminuted fracture of the left acetabulum with medial displacement of the medial acetabular wall (arrow). Residual barium is seen in the colon, sigmoid, and rectum.



### AP PROJECTION\*

Most mobile AP and lateral projections of the femur may be radiographs of the middle and distal femur taken while the patient is in traction. The femur cannot be moved, which presents a challenge to the radiographer.

**Image receptor:** 35 × 43 cm grid lengthwise

#### Position of patient

- The patient is in the supine position.

\*The nonmobile projection is described in Chapter 6.

#### Position of part

- *Cautiously* place the grid lengthwise under the patient's femur with the distal edge of the grid low enough to include the fracture site, pathologic region, and knee joint.
- Elevate the grid with towels, blankets, or blocks under each side, if necessary, to ensure proper grid alignment with the x-ray tube.
- Center the grid to the midline of the affected femur.
- Ensure that the grid is placed parallel to the plane of the femoral condyles (Fig. 30-19).
- *Shield gonads.*
- *Respiration:* Suspend.

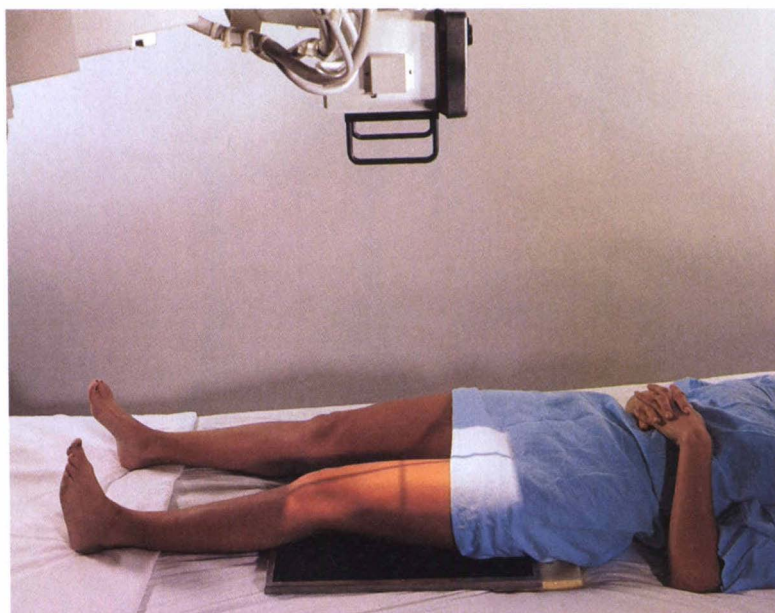


Fig. 30-19 Mobile AP femur.

## Central ray

- Perpendicular to the long axis of the femur and centered to the grid.
- Be certain that the central ray and grid are aligned to prevent grid cutoff.

## COMPUTED RADIOGRAPHY



The thickest portion of the femur (proximal area) must be carefully measured and an appropriate kVp must be selected to penetrate this area. The computer cannot form an image of the anatomy in this area if penetration does not occur. A light area of the entire proximal femur will result. Positioning the cathode over the proximal femur will improve CR image quality.

## Structures shown

The distal two thirds of the femur, including the knee joint, are demonstrated (Fig. 30-20).

## EVALUATION CRITERIA

The following should be clearly demonstrated:

- Majority of femur, including knee joint
- No knee rotation
- Adequate penetration of proximal portion of femur
- Any orthopedic appliance, such as plate and screw fixation

**NOTE:** If the entire length of the femur needs to be visualized, an AP projection of the proximal femur can be performed by placing a 35 × 43 cm grid lengthwise under the proximal femur and hip. The top of the grid is placed at the level of the ASIS to ensure that the hip joint is included. The central ray is directed to the center of the grid and long axis of the femur (see Fig. 30-2).



**Fig. 30-20** Mobile AP femur radiograph showing a fracture of the midshaft with femoral rod placement. Note that the knee joint is included on the image.



Fig. 30-21 Mobile mediolateral left femur. An assistant wearing a lead apron is holding and positioning the right leg and femur and steadying the grid.

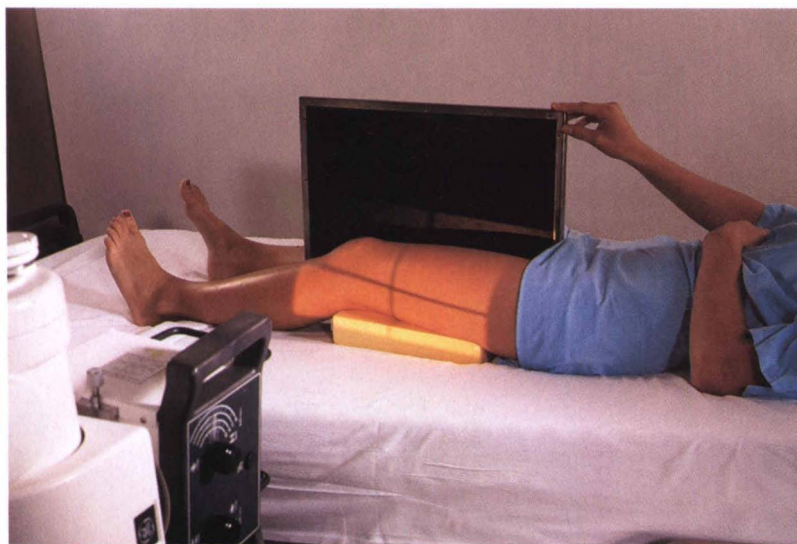


Fig. 30-22 Mobile lateromedial left femur. Note that the grid is placed between the legs and steadied by the patient.



### LATERAL PROJECTION\*

#### Mediolateral or lateromedial Dorsal decubitus position

The femur may not be able to be moved, which presents a challenge to the radiographer. The *mediolateral* projection is generally preferred because more of the proximal femur is demonstrated.

**Image receptor:** 35 × 43 cm grid lengthwise

#### Position of patient

- The patient is in the supine position.

#### Position of part

- Determine whether a mediolateral or lateromedial projection will be performed.

#### Mediolateral projection

- Visualize the optimum length of the patient's femur by placing the grid in a vertical position next to the lateral aspect of the femur.
- Place the distal edge of the grid low enough to include the patient's knee joint.
- Have the patient, if able, hold the upper corner of the grid for stabilization; otherwise, support the grid firmly in position.
- Support the unaffected leg by using the patient's support (a trapeze bar if present) or a support block.
- Elevate the *unaffected* leg until the femur is nearly vertical. An assistant may need to elevate and hold the leg of a critically ill patient. The assistant may also steady the grid and must wear a lead apron for protection (Fig. 30-21).

#### Lateromedial projection

- Place the grid next to the medial aspect of the affected femur (between the patient's legs), and ensure that the knee joint is included (Fig. 30-22).
- Ensure that the grid is placed *perpendicular* to the epicondylar plane.
- *Shield gonads.*
- *Respiration:* Suspend.

\*The nonmobile projection is described in Chapter 6.



## Central ray

- Perpendicular to the long axis of the femur, entering at its midpoint
- Ensure that the central ray and grid are aligned to prevent grid cutoff; the central ray is centered to the femur and not to the center of the grid

## COMPUTED RADIOGRAPHY



The thickest portion of the femur (proximal area) must be measured carefully, and an appropriate kVp must be selected to penetrate this area. The computer cannot form an image of any anatomy in this area if penetration does not occur. A light area of the entire proximal femur will result. Positioning the cathode over the proximal femur will improve CR image quality.

## Structures shown

This projection demonstrates the distal two thirds of the femur, including the knee joint, without superimposition of the opposite thigh (Fig. 30-23).

## EVALUATION CRITERIA

The following should be clearly demonstrated:

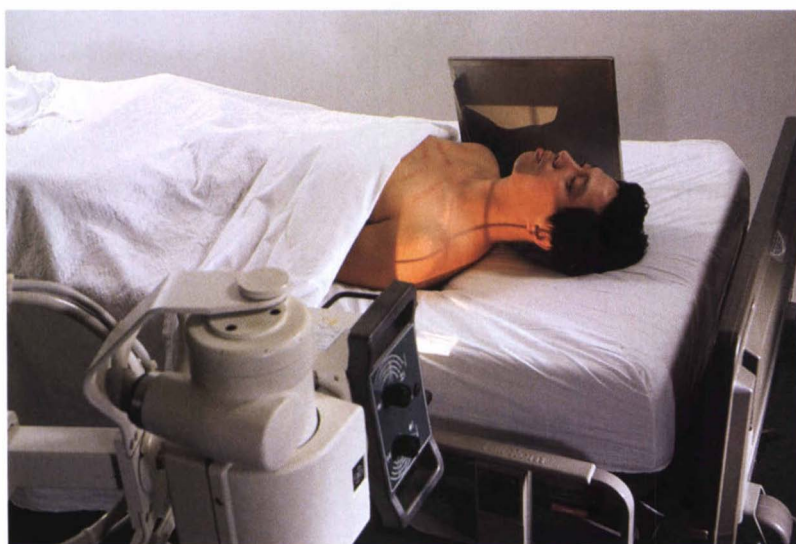
- Majority of femur, including knee joint
- Patella in profile
- Superimposition of femoral condyles
- Opposite femur and soft tissue out of area of interest
- Adequate penetration of proximal portion of femur
- Orthopedic appliance, if present



**Fig. 30-23** Mobile lateral femur radiographs demonstrating midshaft fractures and femoral rod placement. Note that the knee joints are included on the image. **A**, Mediolateral. **B**, Lateromedial.



**Fig. 30-24** Measuring caliper used to hold a 24 × 30 cm (10 × 12 inch) grid in place for mobile lateral cervical spine radiography.



**Fig. 30-25** Mobile lateral cervical spine.

## ▲ LATERAL PROJECTION\*

**Right or left dorsal decubitus position**

**Image receptor:** 10 × 12 inch (24 × 30 cm) grid lengthwise; may be performed with a non-grid IR on smaller patients

### Position of patient

- Position the patient in the supine position with arms extended down along the sides of the body.
- Observe whether a cervical collar or another immobilization device is being used. *Do not remove the device without the consent of the nurse or physician.*

### Position of part

- Ensure that the upper torso, cervical spine, and head are not rotated.
- Place the grid lengthwise on the right or left side, parallel to the neck.
- Place the top of the grid approximately 1 inch (2.43 cm) above the external acoustic meatus (EAM) so that the grid is centered to C4 (upper thyroid cartilage).
- Raise the chin slightly. *In the patient with new trauma, suspected fracture, or known fracture of the cervical region, check with the physician before elevating the chin. Improper movement of a patient's head can disrupt a fractured cervical spine.*
- Immobilize the grid in a vertical position. The grid can be immobilized in multiple ways if a holding device is not available. The best method is to use the measuring caliper. Slide the long portion of the caliper under the shoulders of the patient, with the short end of the caliper pointing toward the ceiling and the grid held between the ends of the caliper (Fig. 30-24). Another method is to place pillows or a cushion between the side rail of the bed and the IR, thereby holding the IR next to the patient. Tape also works well in many instances (Fig. 30-25).
- Have the patient relax the shoulders and reach for the feet, if possible.
- *Shield gonads.*
- *Respiration:* Full expiration to obtain maximum depression of the shoulders.

\*The nonmobile projection is described in Chapter 8.

## Central ray

- Horizontal and perpendicular to the center of the grid. This should place the central ray at the level of C4 (upper thyroid cartilage).
- Ensure that proper alignment of the central ray and grid is maintained to prevent grid cutoff.
- Because of the great object-to-image distance (OID), a SID of 60 to 72 inches (158 to 183 cm) is recommended. This also helps to demonstrate C7.

## COMPUTED RADIOGRAPHY



To ensure that the lower cervical vertebrae are fully penetrated, the kVp must be set to penetrate the C7 area.

## Structures shown

This projection demonstrates the seven cervical vertebrae, including the base of the skull and the soft tissues surrounding the neck (Fig. 30-26).

## EVALUATION CRITERIA

The following should be clearly demonstrated:

- All seven cervical vertebrae, including interspaces and spinous processes
- Neck extended when possible so that rami of mandible are not overlapping C1 or C2
- C4 in center of grid
- Superimposed posterior margins of each vertebral body

**NOTE:** It is essential that C6 and C7 be included on the image. To accomplish this, the radiographer should instruct the patient to relax the shoulders toward the feet as much as possible. If the examination involves pulling down on the patient's arms, the radiographer should exercise extreme caution and evaluate the patient's condition carefully to determine whether pulling of the arms can be tolerated. Fractures or injuries of the upper limbs, including the clavicles, must be considered. Furthermore, applying a strong pull to the arms of a patient in a hurried or jerking manner can disrupt a fractured cervical spine. If the lateral projection does not adequately visualize the lower cervical region, the Twining method, sometimes referred to as the "swimmers" position, which eliminates pulling of the arms, may be recommended for individuals who have experienced trauma or have a known cervical fracture. One arm must be placed above the patient's head (see Twining method, Chapter 8).



A



B



C

**Fig. 30-26** Mobile lateral cervical spine radiographs performed at the patient's bedside several weeks after trauma. **A**, Entire cervical spine shows slight anterior subluxation of the dens on the body of C2 (arrow). **B**, Entire cervical spine shows a nearly vertical fracture through the body of C5 with slight displacement (arrow). **C**, The first five cervical vertebrae show vertical fractures through posterior aspects of C2 laminae (arrow) with 4-mm displacement of the fragments. Earlier radiographs demonstrated that C6 and C7 were unaffected and did not need to be included in this follow-up radiograph.



### AP PROJECTION

The chest and abdomen combination described here is typically ordered for neonatal premature infants who are in the neonatal intensive care unit. If a chest or abdomen projection is ordered separately, the radiographer should adjust the central ray and collimator accordingly.

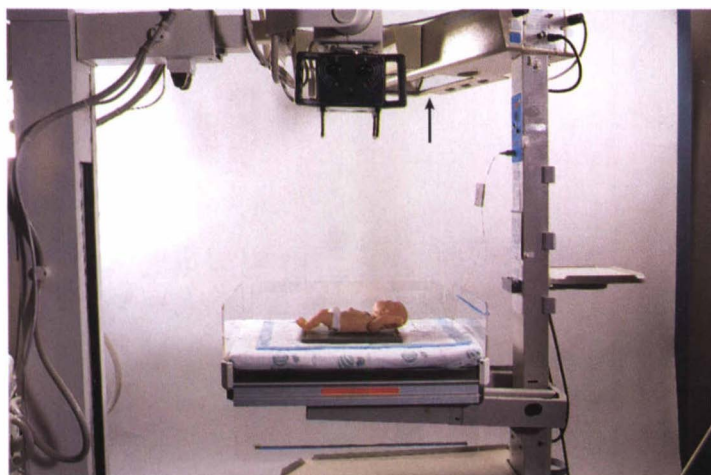
**Image receptor:** 8 × 10 inch (20 × 24 cm) lengthwise

#### Position of patient

Position the infant supine in the center of the IR. Some bassinets have a special tray to hold the IR. Positioning numbers along the tray permits accurate placement of the IR (Fig. 30-27). If the IR is directly under the infant, cover it with a soft, warm blanket.



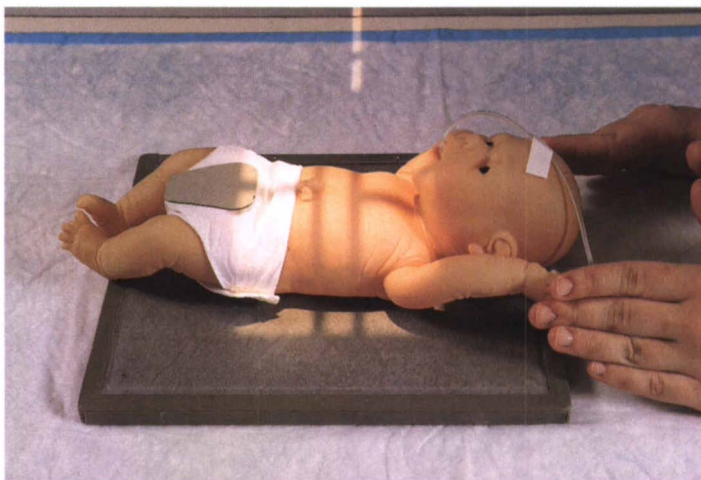
**Fig. 30-27** IR being placed on a special tray for placement below the infant. Numbers along the side of tray correspond with numbers along the side of the bed railing to allow accurate positioning of the IR.



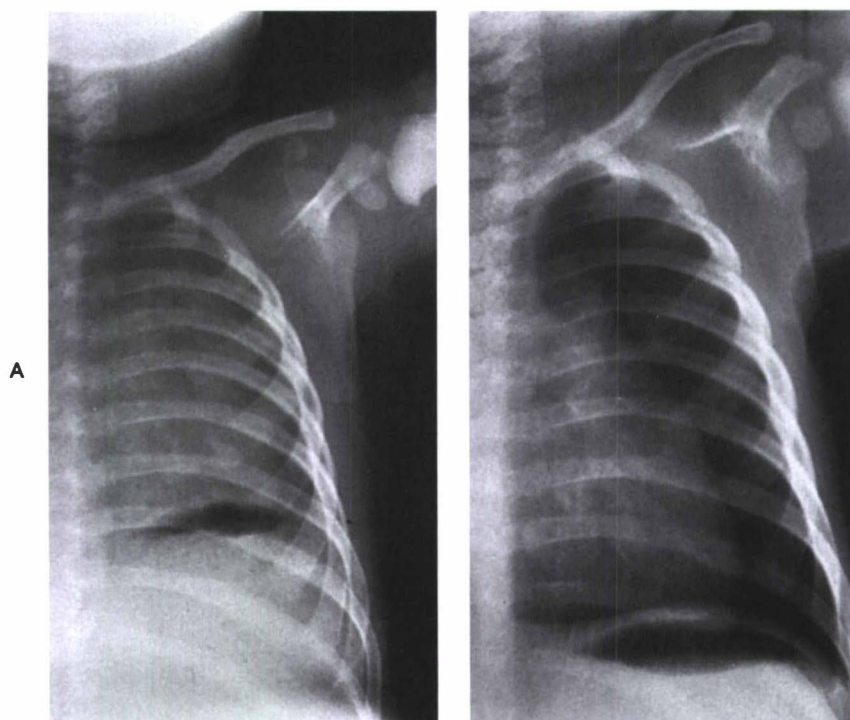
**Fig. 30-28** Neonatal intensive care unit bassinet with premature infant. Overhead heating unit (arrow) is moved out of the way to accommodate the mobile x-ray machine tube head.

### Position of part

- Carefully position the x-ray tube over the infant (Fig. 30-28).
- Ensure that the chest and abdomen are not rotated.
- Move the infant's arms away from the body or over the head and bring the legs down and away from the abdomen. The arms and legs may have to be held by a nurse, who should wear a lead apron.
- Leave the head of the infant rotated. (See note at end of this section.)
- Adjust the collimators closely to the chest and abdomen (Fig. 30-29).
- Shield gonads.
- **Respiration:** Inspiration. The neonatal infant has an extremely fast respiratory rate and cannot hold the breath. Make the best attempt possible to perform the exposure on full inspiration (Fig. 30-30).



**Fig. 30-29** Mobile chest and abdomen radiograph of neonate. Note the male gonad shield. (In actual practice the IR is covered with a soft, warm blanket.)



**Fig. 30-30** Radiographs on inspiration and expiration in a neonatal infant. **A**, Left side of chest is shown at full expiration. Note the lack of normal lung markings and the illusion of massive pulmonary disease. The diaphragm is not seen, and the heart appears enlarged. **B**, Repeat radiograph of the same patient performed correctly at full inspiration. The diaphragm may be seen correctly at the level of the tenth posterior rib. The same technical factors were used for both exposures.

(Courtesy Department of Radiology, Rochester General Hospital, Rochester, NY; from Cullinan AM, Cullinan JE: *Producing quality radiographs*, ed 2, Philadelphia, 1994, Lippincott.)

### Central ray

- Perpendicular to the midpoint of the chest and abdomen along the midsagittal plane

### Structures shown

The anatomy of the entire chest and abdomen is demonstrated (Fig. 30-31).

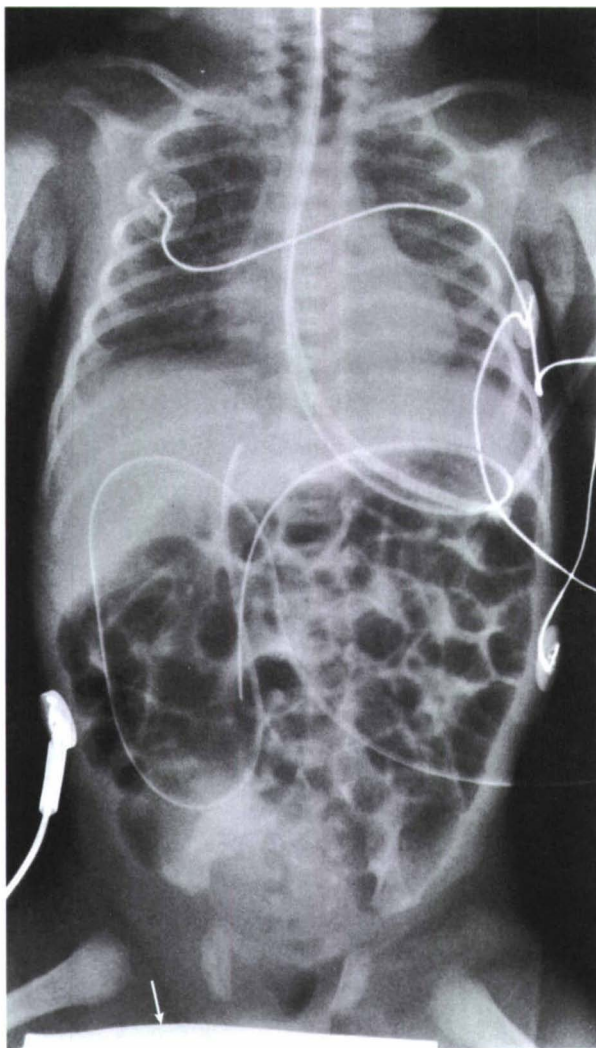
### EVALUATION CRITERIA

The following should be clearly demonstrated:

- Anatomy from apices to pubic symphysis in the thoracic and abdominal regions
- No motion
- No blurring of lungs, diaphragm, and abdominal structures
- No rotation of patient

**NOTE:** When performing an AP or lateral projection of the chest, the radiographer should keep the head and neck of the infant straight so that the anatomy in the upper chest and airway is accurately visualized. However, straightening the head of a neonatal infant in the supine position can inadvertently advance an endotracheal tube too far into the trachea. Therefore it is sometimes more important to leave the head of an intubated neonatal patient rotated in the position in which the infant routinely lies to obtain accurate representation of the position of the endotracheal tube on the radiograph.





**Fig. 30-31** Mobile AP chest and abdomen radiograph of a neonate. The exposure technique demonstrates the anatomy of the entire chest and abdomen. Note the gonad shield accurately positioned on this male infant (*arrow*).



### LATERAL PROJECTION

#### Right or left dorsal decubitus position

**Image receptor:** 8 × 10 inch (20 × 24 cm) lengthwise

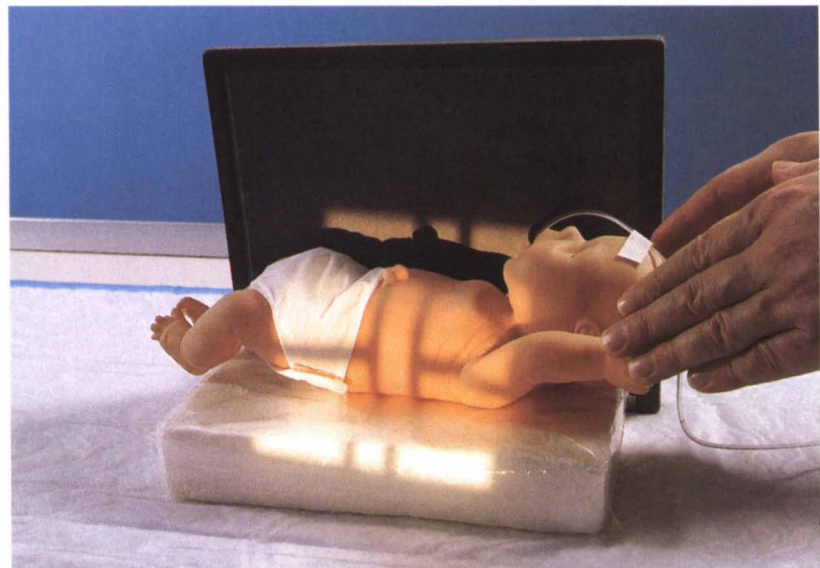
Most neonatal premature infants cannot be turned on their sides or placed upright for a lateral projection.

#### Position of patient

- *Carefully* place the x-ray tube to the side of the bassinet.
- Position the infant supine on a radiolucent block covered with a soft, warm blanket. If a radiolucent block is not readily available, an inverted box of tissues works well.

#### Position of part

- Ensure that the infant's chest and abdomen are centered to the IR and not rotated.
- Move the infant's arms above the head. The arms will have to be held up by a nurse, who should wear a lead apron.
- Place the IR lengthwise and vertical beside the patient and then immobilize it.
- Leave the head of the infant rotated. (See note on p. 260).
- Adjust the collimators closely to the chest and abdomen (Fig. 30-32).
- *Shield gonads.*
- *Respiration:* Inspiration. The neonatal infant has an extremely fast respiratory rate and cannot hold the breath. Make the best attempt possible to perform the exposure on full inspiration.



**Fig. 30-32** Mobile lateral chest and abdomen of a neonate in the dorsal decubitus position. The infant is positioned on a raised block with the IR below the block.

### Central ray

- Horizontal and perpendicular to the midpoint of the chest and abdomen along the midcoronal plane

### Structures shown

This projection demonstrates the anatomy of the entire chest and abdomen, with special attention to the costophrenic angles in the posterior chest. If present, air and fluid levels are visualized (Fig. 30-33).

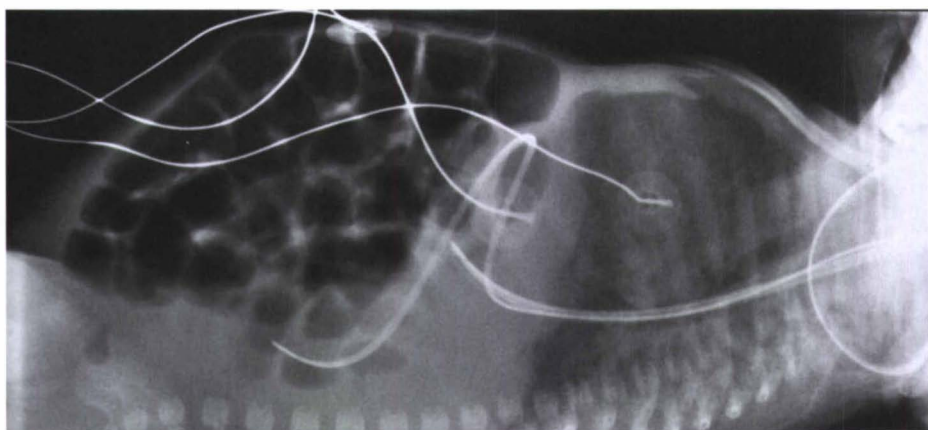
### EVALUATION CRITERIA

The following should be clearly demonstrated:

- Anatomy of chest and abdomen from apices to pubic bone
- No motion
- No blurring of lungs, diaphragm, and abdominal structures
- No rotation of patient
- Air and fluid levels, if present

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**Fig. 30-33** Mobile lateral chest and abdomen radiograph of a neonate in the dorsal decubitus position. The exposure technique demonstrates the anatomy of the entire chest and abdomen.





31

# SURGICAL RADIOGRAPHY

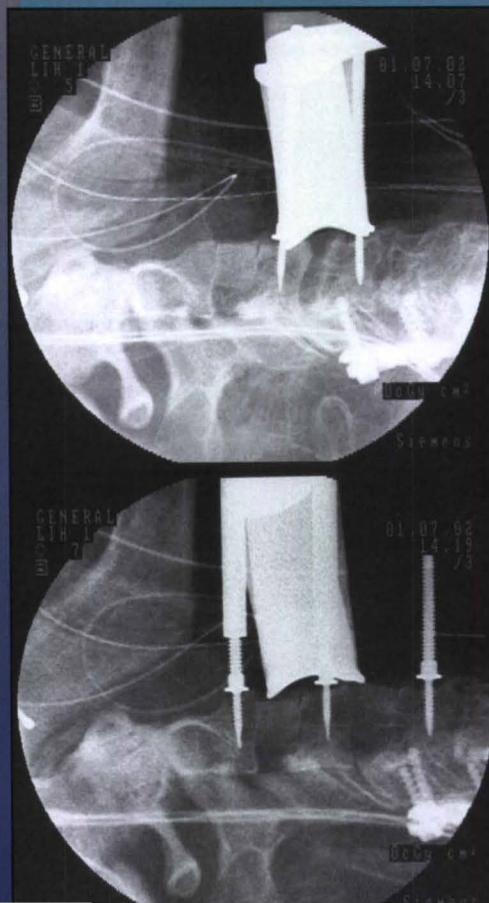
KARI J. WETTERLIN

JOEL PERMAR

Fluoroscopic image of cervical spine in lateral projection showing plate and screws used to fuse two vertebra.

## Outline

The surgical team, 266  
Proper surgical attire, 268  
Operating room attire, 269  
The dance of the OR, 270  
Equipment, 274  
Cleaning of the equipment, 275  
Fluoroscopic procedures  
for the operating room, 275  
Mobile radiography procedures  
for the operating room, 296  
Definition of terms, 303



Surgical radiology is a unique experience. The challenges a radiographer encounters in the surgical suite are unique. Knowing the machinery and its capabilities and limitations is most important; in that regard, the radiographer can enter any operating room (OR) case, whether routine or unique and, with good communication, be able to perform all tasks well. An understanding of common procedures and familiarity of equipment enables the radiographer to perform most mobile examinations ordered by the physician. Surgical radiography can be a challenging and exciting environment for the radiographer; but can also be intimidating and stressful. Surgical radiology requires educated personnel familiar with specific equipment routinely used during common surgical procedures. It requires expertise in teamwork. Preparedness and familiarity of equipment is key. There are also standard health and safety protocols that must be followed to avoid contamination and to ensure patient safety. These are the basics, and the pieces come together in surgical radiology in unique ways.

This chapter focuses on the most common procedures performed in the surgical area, the basic principles of mobile imaging are detailed, and helpful suggestions are provided for successful completion of the examinations. It is not the intent of this chapter to cover every possible combination of examinations or situations that a radiographer may encounter, but rather to provide an over view of the surgical setting, as well as a summary of common examinations. The scope of radiologic examinations in a surgical setting is vast and may differ greatly between health care facilities (Box 31-1). Therefore the goals of this chapter include the following: (1) provide an over view of the surgical setting and explain the role of the radiographer as a vital member of the surgical team, (2) assist the radiographer in developing an understanding of the imaging equipment utilized in surgical situations, and (3) present common radiographic procedures performed in the OR.

## The Surgical Team

At no other time will the patient be so well attended as during the surgical procedure. A surgeon, one or two assistants, a surgical technologist, an anesthesia provider, a circulating nurse, and various support staff surround the patient. These individuals, each with specific functions to perform, form the operating room team. This team literally has the patient's life in its hands. The OR Team has been described like a symphony orchestra, with each person an integral entity in unison and harmony with his or her colleagues for the successful accomplishment of the expected outcomes. The OR team is subdivided, according to the functions of its members, into sterile and non-sterile teams.

### BOX 31-1

#### Scope of surgical radiography

##### Surgical fluoroscopic procedures

- Abdomen: cholangiogram
- Chest-line placement: bronchoscopy
- C-spine: anterior cervical disectomy and fusion (ACDF)
- Lumbar spine
- Hip: cannulated hip screws or hip pinning, decompression hip screw (DHS)
- Femoral and tibial nailing
- Extremity fluoro
- Humerus: shoulder in beach chair position
- Transphenoidal resection of pituitary tumor
- Femoral/tibial arteriogram

##### Mobile surgical radiography procedures

- Localization examinations of cervical, thoracic and lumbar spine
- Mobile extremity examinations in the operating room



## STERILE TEAM MEMBERS

Sterile team members scrub their hands and arms, don a sterile gown and gloves over proper surgical attire, and enter the sterile field. The sterile field is the area of the OR that immediately surrounds and is specially prepared for the patient. To establish a sterile field, all items needed for the surgical procedure are sterilized. After this process, the scrubbed and sterile team members' function within this limited area and handle only sterile items (Fig. 31-1). The sterile team consists of the following members:

- **Surgeon:** The surgeon is a licensed physician who is specially trained and qualified by knowledge and experience to perform surgical procedures. The surgeon's responsibilities include preoperative diagnosis and care, selection and performance of the surgical procedure, and postoperative management of care. The surgeon assumes full responsibility for all medical acts of judgment and for the management of the surgical patient.
- **Surgical Assistant:** The first assistant is a qualified surgeon or resident in an accredited surgical educational program. The assistant should be capable of assuming responsibility for performing the procedure for the primary surgeon. Assistants help to maintain visibility of the surgical site, control bleeding, close wounds, and apply dressings. The assistant's role varies depending on the institution, as well as with the type of procedure or surgical specialty.
- **Physicians Assistant:** The Physicians Assistant (PA) is a non-physician allied health practitioner who is qualified by academic and clinical training to perform designated procedures in the OR and in other areas of surgical patient care.
- **Certified Surgical Technologist:** The Certified Surgical Technologist (CST) is responsible for maintaining the integrity, safety, and efficiency of the sterile field throughout the surgical procedure. The CST prepares and arranges instruments and supplies and facilitates the surgical procedure by providing the required sterile instruments and supplies. In some institutions an LPN or RN may assume this role.



Fig. 31-1 Operating room staff showing sterile (*left*) and non-sterile (*right*) team members.

## NON-STERILE TEAM MEMBERS

Non-sterile team members do not enter the sterile field; they function outside and around it. They assume responsibility for maintaining sterile techniques during the surgical procedure, but they handle supplies and equipment that are not considered sterile. Following the principles of aseptic technique, they keep the sterile team supplied, provide direct patient care, and handle other requirements that may arise during the surgical procedure.

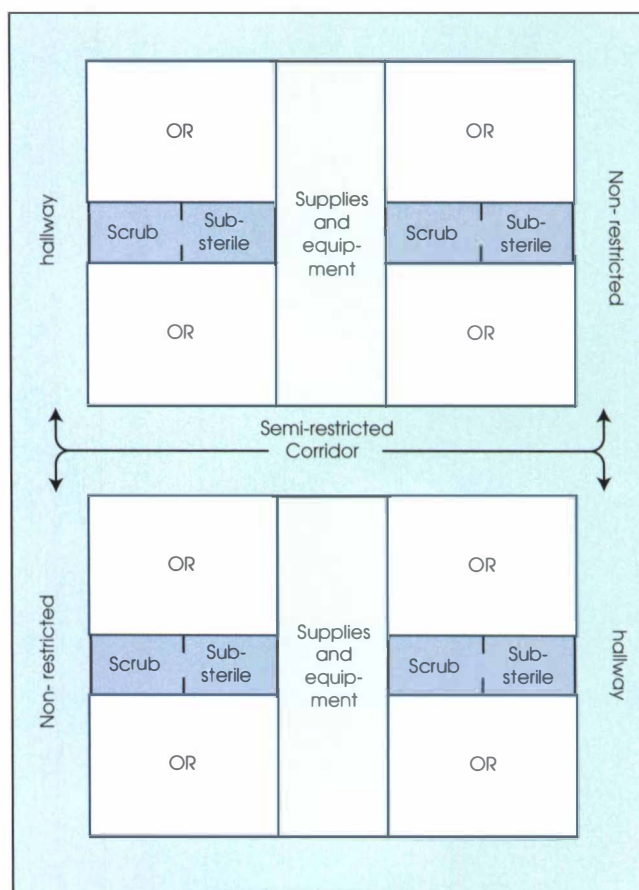
- **Anesthesia Provider:** The anesthesia provider is an MD (Anesthesiologist) or Certified Registered Nurse Anesthetist who specializes in the art and science of administering anesthetics. Choosing and applying appropriate agents and suitable techniques of administration, monitoring physiologic functions, maintaining fluid and electrolyte balance, and performing blood replacements are essential responsibilities of the anesthesia provider during the surgical procedure.

- **Circulator:** The circulator is preferably a Registered Nurse (RN). The circulator monitors and coordinates all activities within the OR and provides supplies to the CST during the surgical procedure, as well as managing the care of the patient.
- **Radiographers:** The radiographer's role in the OR is to provide intraoperative imaging in a variety of examinations and with various types of equipment.
- **Others:** The OR team may also include biomedical technicians, monitoring technologists, and individuals specialized in equipment or monitoring devices necessary during the surgical procedure.

## Proper Surgical Attire

Surgical attire protocols may change from institution to institution, but should be available for review, understood, and followed by all staff. Although some small variances in protocol exist between institutions, there are common standards.

Large amounts of bacteria are present in the nose and mouth, on the skin, and on the attire of personnel who enter the restricted areas of the surgical setting. Proper facility design and surgical attire regulations are important ways of preventing transportation of microorganisms into surgical settings, where they may infect patients' open wounds. Infection control practices also involve personal measures including personal fitness for work, skin disinfection (patient and personnel), preparation of personnel hands, surgical attire, and personal technique (surgical conscience). Daily body cleanliness and clean, dandruff-free hair help prevent superficial wound infections.



**Fig. 31-2** Schematic of the operating room layout showing non-restricted, and semi-restricted areas. The eight OR rooms are "restricted."

## Operating Room Attire

The OR should have specific written policies and procedures for proper attire to be worn within the semi-restricted and restricted areas of the OR suite. The dress code should include aspects of personal hygiene important to environmental control. Protocol is strictly monitored so that everyone conforms to established policy.

Street clothes should never be worn within semi-restricted or restricted areas of the surgical suite (Fig. 31-2). Clean, fresh attire should be donned at the beginning of each shift in the OR suite and as necessary if the attire becomes wet or grossly soiled. Soiled surgical attire should be changed to reduce the potential of cross-infection. Bloodstained or soiled attire, including shoe covers, is unattractive and can also be a source of cross-infection or contamination. Soiled attire is not worn outside of the OR suite and steps should be taken to remove soiled clothing immediately upon exiting. OR attire should not be hung in a locker for wearing a second time. Underclothing should be clean and totally covered by the scrub suit (Fig. 31-3). Other aspects of proper attire include:

- **Protective Eyewear:** OSHA regulations require eyewear to be worn when contamination from blood or body fluids is possible.
- **Masks:** Masks should be worn at all times in the OR, but are not necessary in all semi-restricted areas.
- **Shoe covers:** Shoe covers should be worn when contamination from blood or body fluids can be reasonably anticipated. Shoe covers should be changed whenever they become torn, soiled, or wet and should be removed before leaving the surgical area.
- **Caps:** Caps should be worn to cover and contain hair at all times in the restricted and semi-restricted areas of the OR suite. Hoods are also available to cover hair, such as facial hair, that can not be contained by a cap and mask.
- **Gloves:** Gloves should be worn when there is anticipated contact with blood or body substances.
- **Radiation badge and proper identification** should be worn at all times.

## PERSONAL HYGIENE

A person with an acute infection, such as a cold, open cold sore, or sore throat, is known to be a carrier of transmittable conditions and should not be permitted within the OR suite. Daily body cleanliness and clean hair is also very important since good personal hygiene helps to prevent transportation of microbial fallout that can cause open wound infections.



**Fig. 31-3** Properly attired radiographers including protective eyewear.



## The Dance of the OR

The concepts of sterile and aseptic technique are recorded as far back in history as Hippocrates in which he boiled wine and water to pour into open wounds in attempts of preventing infection. Galen changed technique a bit and began boiling the instruments instead, and shortly after, Semmelweis noted a dramatic decline in postoperative infection by having the staff wash their hands and change gowns in between the surgical patients.

Maintaining the sterile field in an operating suite can be like a well-choreographed dance when the team is working well together. There are certain moves and rules that must be followed. Proper adherence to aseptic technique eliminates or minimizes modes and sources of contamination. Basic principles must be observed during the surgical procedure to provide the patient with a well-defined margin of safety. Everyone who cares for patients must carry out effective hospital and operating room infection control programs. Infection control involves a wide variety of concepts including methods of environmental sanitation and maintenance of facilities; cleanliness of the air and equipment in the suite; cleanliness of the skin and apparel of patients, surgeons, and personnel; sterility of surgical equipment; strict aseptic technique; and careful observance of procedural rules and regulations.

Up to 10,000 microbial particles can be shed from the skin per minute. Therefore non-sterile team members should not reach over a sterile field. When working over the sterile field, performing a PA Lumbar spine for example, the sterile field should be covered with a sterile drape to protect the field (Fig. 31-4). Once the sterile cover is in place, only then can the technologist move the radiographic equipment into position over the sterile field. A sterile team member should fold over the sterile drape on itself and then a non-sterile team member should carefully remove the covering drape being careful not to compromise the sterile field.



**Fig. 31-4** Radiographer leaning over the sterile field while positioning the x-ray tube. The sterile incision site over which the radiographer works is properly covered to maintain a sterile field. Note the sterile instruments in the foreground (arrow). The radiographer should never move radiographic equipment over uncovered sterile instruments or an uncovered surgical site.

If a sterile field is compromised, the OR staff should be notified immediately.

Communication is of utmost importance. As a result of the surgical sterile field, the radiographer is unable to help position the IR or the patient. Therefore good, professional communication is essential while using sound basic knowledge of anatomy and positioning. The radiographer may have to instruct the surgeon or resident toward the proper position to best visualize the desired portion of the anatomy. For example, a surgeon or resident may not be aware of the exact rotation and foot flexion required to achieve a proper mortise view of the ankle.

### PROPER IR HANDLING IN THE STERILE FIELD

To maintain proper universal precautions, the radiographer must follow specific steps when handling an IR in the operating room.

Surgical Technologist (CST) taking the IR: The CST will hold a sterile IR cover open toward the radiographer. The radiographer should hold one end of the IR while placing the other end of the IR into the sterile IR cover. The CST will grasp the IR and wrap the protective cover securely (Fig. 31-5).

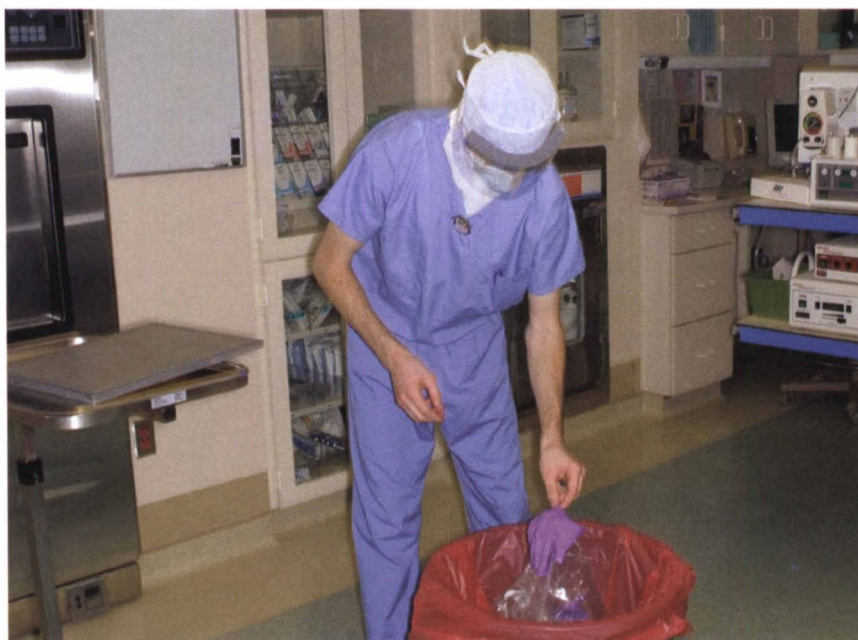


Fig. 31-5 Radiographer and CST exchange the IR into the sterile drape.

A



B



**Fig. 31-6 A,** Radiographer correctly removes the IR from the now contaminated bag to a clean table being careful not to brush contaminants from bag onto self or others. **B,** Radiographer disposes of bag and removes contaminated gloves before handling the IR.



Radiographer accepting the IR after exposure: After the exposure is made, the radiographer will need to retrieve the IR. The radiographer must be wearing gloves to accept a covered IR that has been in the sterile field or under an open incision. The protective cover is possibly contaminated with blood or body fluids and should be treated accordingly. The radiographer should grasp the IR, open the protective cover carefully away from self or others so as not to spread blood or body fluids, then slide the IR out of the cover (Fig. 31-6). Dispose of the IR cover in a proper receptacle and remember to remove the gloves before handling the IR or any other equipment because the gloves are now considered contaminated. If contamination of the IR occurs, use hospital approved disinfectant for cleaning before leaving the OR (Box 31-2).

### ENEMIES OF THE STERILE FIELD

Lengthy or complex procedures increase the chance of sterile field contamination. Physical limitations such as crowding, poor lighting, and staffing levels are also a consideration. The floor is always considered contaminated. Therefore avoid placing IRs, lead aprons, and shields on the floor.

#### BOX 31-2

##### Principles of aseptic techniques

- Only sterile items are used within the sterile field.
- Sterile persons only handle sterile items or touch sterile areas.
- Non-sterile persons touch only unsterile items or areas.
- Movement within or around a sterile field must not contaminate the sterile field.
- Items of doubtful sterility must be considered unsterile.
- When a sterile barrier is permeated, it must be considered contaminated.
- Sterile gowns are considered sterile in front from shoulder to the level of the sterile field, and at the sleeves from the elbow to the cuff.
- Tables are sterile only at table level.
- Radiographers should not walk between two sterile fields when at all possible.
- Radiographers should avoid turning their back toward the sterile field in compromised spaces.
- Watch the front of clothing when it is necessary to be next to the patient.
- Be aware of machinery close to the sterile field including lead aprons hanging from the portable machine that may swing toward the sterile field.
- Secure the lead apron if wearing it next to the sterile field. It is easy for the apron to slip forward when raising ones arms up to position the tube. A properly worn apron does not compromise the sterile field or jeopardize proper body mechanics.
- When positioning an IR under the OR table, the radiographer should not lift the sterile drapes above table level, since this would compromise the sterile field.



Fig. 31-7 In-room urologic radiographic equipment used for retrograde ureterograms.



Fig. 31-8 C-arm radiographic/fluoroscopic system used in the OR.

## Equipment

It is important for the radiographer to be well acquainted with the radiologic equipment. Some procedures may seldom occur. The radiographer need not fear a rare procedure if good communication and equipment knowledge is in place. IR holders enable the radiographer to perform cross-table projections on numerous cases, and eliminate the unnecessary exposure of personnel who may volunteer to hold the IR. In mobile radiography, exposure times may increase for larger patients and a holder eliminates the chance of motion from hand-held situations.

Some operating suites, such as those used for stereotactic or urologic cases, have dedicated radiologic equipment (Fig. 31-7). However, a majority of the radiographic examinations in the OR are performed with mobile equipment.

Mobile image machines are not as sophisticated as larger stationary machines in the radiology department. Mobile fluoroscopic units, many times referred to as C-arms because of their shape (Fig. 31-8), are commonplace in the surgical suite. Mobile radiography is also widely used in the operating room.

## Cleaning of the Equipment

The x-ray equipment should be cleaned after every surgical case. If at all possible, the radiographer should clean the mobile image machine, including the base, in the OR suite especially when the equipment is obviously contaminated with blood or Betadine solution. Cleaning within the OR helps reduce the possibility of cross contamination. The x-ray equipment is to be cleaned with a hospital approved cleaning solution. Cleaning solutions should not be sprayed in the OR suite during the surgical procedure. If cleaning is needed during the surgical procedure, opening the cleaning container and pouring the solution on a rag for use prevents possible contamination from scattered spray. Gloves should always be worn during cleaning. The under side of the image machine should be checked to make sure contaminants that might have splashed up from the floor are removed. It is necessary to clean the equipment after an isolation case to prevent the spread of contaminants. It is recommended that all less-used equipment undergo a thorough cleaning at least once a week and just before it is taken into the OR.

## Fluoroscopic Procedures for the Operating Room

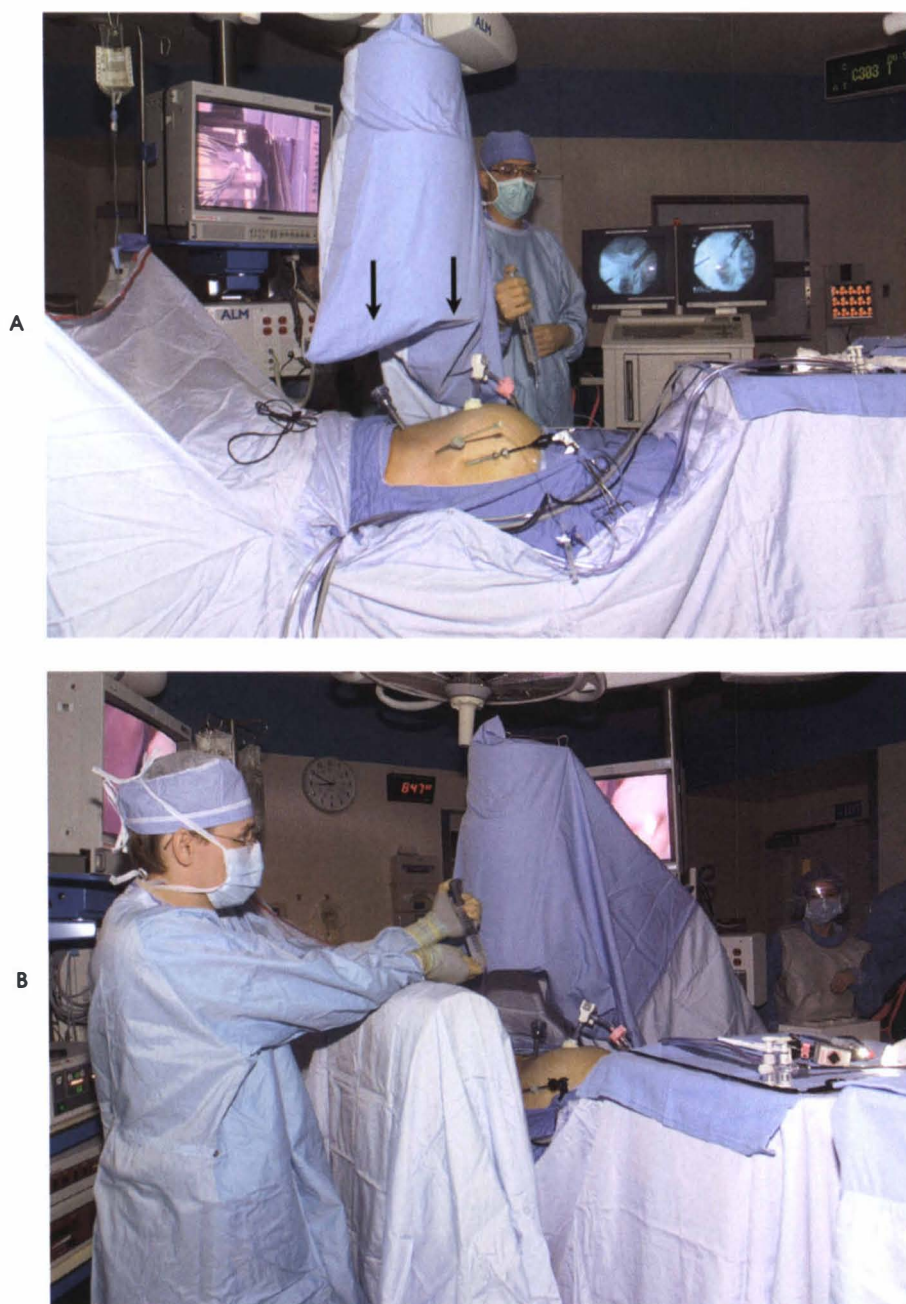
### OPERATIVE (IMMEDIATE) CHOLANGIOGRAPHY

Operative cholangiography, introduced by Mirizzi in 1932, is carried out during biliary tract surgery. After the bile has been drained, and in the absence of obstruction, this technique permits the major intrahepatic ducts and the extrahepatic ducts to be filled with contrast medium.

The value of operative cholangiography is such that it has become an integral part of biliary tract surgery. It is used to investigate the patency of the bile ducts and the functional status of the sphincter of the hepatopancreatic ampulla to reveal the presence of calculi that cannot be detected by palpation and to demonstrate such conditions as small intraluminal neoplasms and stricture or dilation of the ducts. When the pancreatic duct shares a common channel with the distal common bile duct before emptying into the duodenum, it is sometimes seen on operative cholangiograms because it has been partially filled by reflux.

After exposing, draining, and exploring the biliary tract, and frequently after excising the gallbladder, the surgeon injects the contrast medium. This solution is usually introduced into the common bile duct through a needle, small catheter, or, after cholecystectomy, through an inlaying T tube. When the latter route is used, the procedure is referred to as delayed operative or operative T-tube cholangiography.





**Fig. 31-9 A,** C-arm in correct position for an abdominal cholangiogram. Assistant surgeon checks syringe for air bubbles prior to handing to surgeon for injection. Note, radiographer positioned the fluoroscopic image intensifier (*arrows*) carefully to avoid hitting laparoscopic instruments protruding from the patient's abdomen. **B,** Surgeon standing behind a sterile draped lead shield injecting contrast media for an operative cholangiogram.

### Position of patient

Patient is supine with the abdomen exposed. In laparoscopic cases such as cholecystectomy, the abdomen is distended since air is injected into the abdominal cavity to allow adequate room for maneuvering of the camera and instruments. Make sure there are no obstacles that will impede the movement of the C-arm (Fig. 31-9).

**NOTE:** Shield pregnant patients. Remember the central ray comes from under the table so the lead shield should be placed under the patient, and placed so as not to obscure any pertinent anatomy.

### Position of C-arm

Center the C-arm in the PA position over the right side of the abdomen below the rib line. Patient may be tilted to the left or in the Trendelenburg position to aid in the flow of contrast to the complete biliary system. Tilt or cant the C-arm until PA position is achieved. The C-arm may also have to be rotated to ensure that the spine does not obscure the biliary system. Once position is obtained, the surgeon injects contrast into the duct system under fluoroscopy.

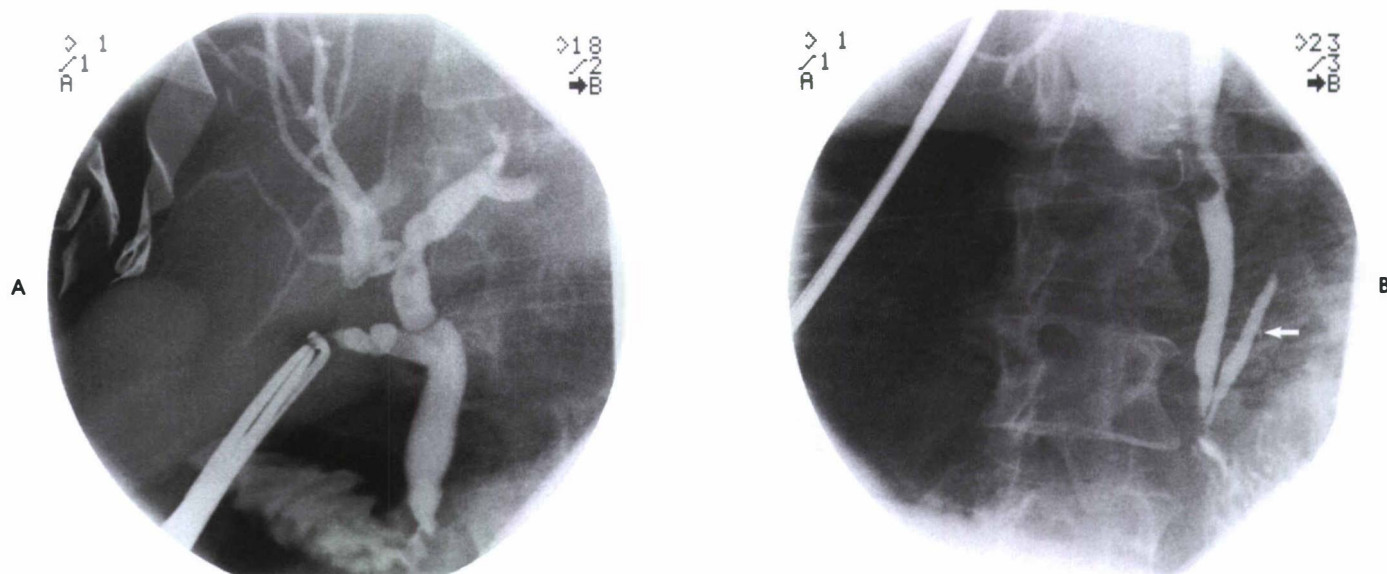
- Provide radiation protection for all persons in the room.
- Bring an adequate number of IRs for immediate processing of all images
- Examination is optimal with suspended respiration but due to length of time it may take for contrast to fill all ducts, respiration may be continued throughout the examination.

### Structures shown

This examination shows the biliary system full of contrast, including a portion of the cystic duct, the branches of the hepatic duct, the common bile duct, and often the pancreatic duct.

### EVALUATION CRITERIA

- The biliary system should be completely filled with contrast (Fig. 31-10).
- No extravasation of contrast at the injection site.
- Biliary system should not be obscured by any extraneous anatomy or instrumentation.
- Prompt emptying of contrast into the duodenum.
- Proper radiographic technique is maintained.
- Sterile field is maintained.



**Fig. 31-10** Hard copy images of anatomy visualized during a cholangiogram using fluoroscopy. **A**, Intraoperative cholangiogram. **B**, Intraoperative cholangiogram showing the pancreatic duct (arrow).

## CHEST (LINE PLACEMENT, BRONCHOSCOPY)

### Position of patient

Patient is supine with the arms secured at his or her sides. Be certain there are no bars or supports in the table that will obscure view of chest. Allow room under the table for the C-arm to maneuver.

### Position of C-arm

Cover the C-arm with sterile drape before entering field. The C-arm will enter the sterile field perpendicular to the patient. If the surgeon prefers, reverse or invert the image to obtain AP view. Provide radiation protection for all persons in room.

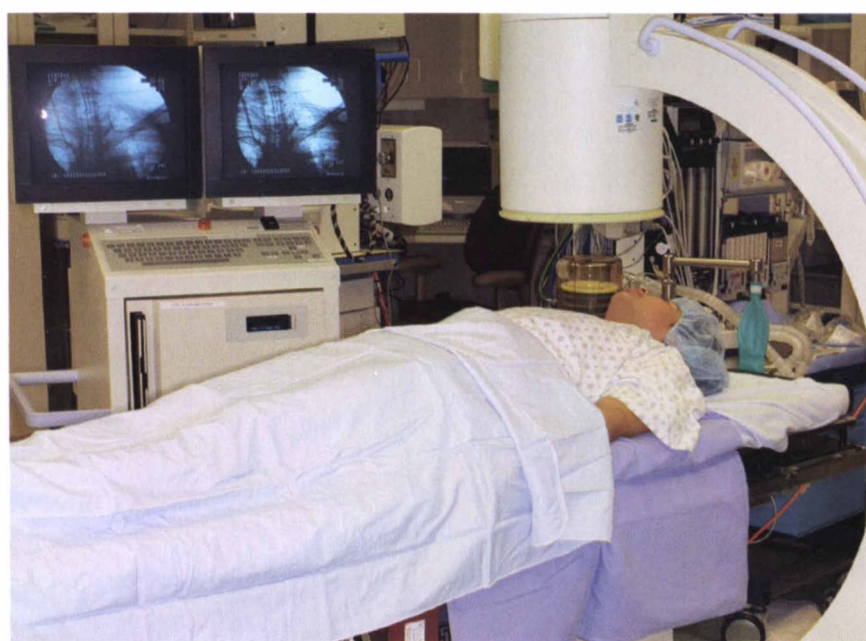
- Line placement: Find the point of insertion and follow the catheter to its end. This examination is done to ensure there are no kinks in the catheter and to show it is in proper position. There are a number of catheters that may be utilized in the OR. They are usually inserted to deliver medicines to chronically ill patients.
- Rigid and Flexible Bronchoscopy: May be done to perform biopsies, place stents, or dilate the bronchi.

### Structures shown

All anatomy of the chest cavity including the heart, lung fields, and ribs and any instrumentation that may be introduced during the procedure. These may include catheters, guide wires, bronchoscopes, stent devices, dilatation balloons, or biopsy instruments.

### EVALUATION CRITERIA

- Pertinent parts of the chest are distinguished easily (Fig. 31-11).
- Proper radiographic technique and contrast maintained on the monitor.
- Image on monitor is in true AP position.
- Sterile technique is maintained.



**Fig. 31-11** Patient and C-arm in position for a Hickman catheter placement. Introduction of the catheter begins in the upper thorax and is completed with the catheter in the heart.



## C-SPINE (ACDF)

### Position of patient

Patient is supine with the chin elevated and the neck in flexion. Patient's arms will be at his or her sides and may be pulled in traction to help keep the shoulders from obscuring the spine.

### Position of C-arm

#### PA projection

Cover the C-arm with sterile drape. Enter the sterile field perpendicular to the patient. Tilt the C-arm 15 degrees cephalad and center the beam over the C-spine. Raise the C-arm to allow the surgeon to work if necessary. Make sure the spine is in the center of the monitor and top of spine and skull are at the top of the screen with no rotation.

### Lateral projection

Rotate the C-arm under the table into lateral position with the beam parallel to the floor. Angle the C-arm either cephalad or caudal to obtain true lateral view. Raise or lower the C-arm to bring the spine into the center of field of view. Rotate the image on the monitor to the same plane as the patient with the spine parallel with the floor. Cases in which an PA projection are not needed may opt to have the C-arm positioned in "rainbow" fashion, or arced over the patient (Fig. 31-12).

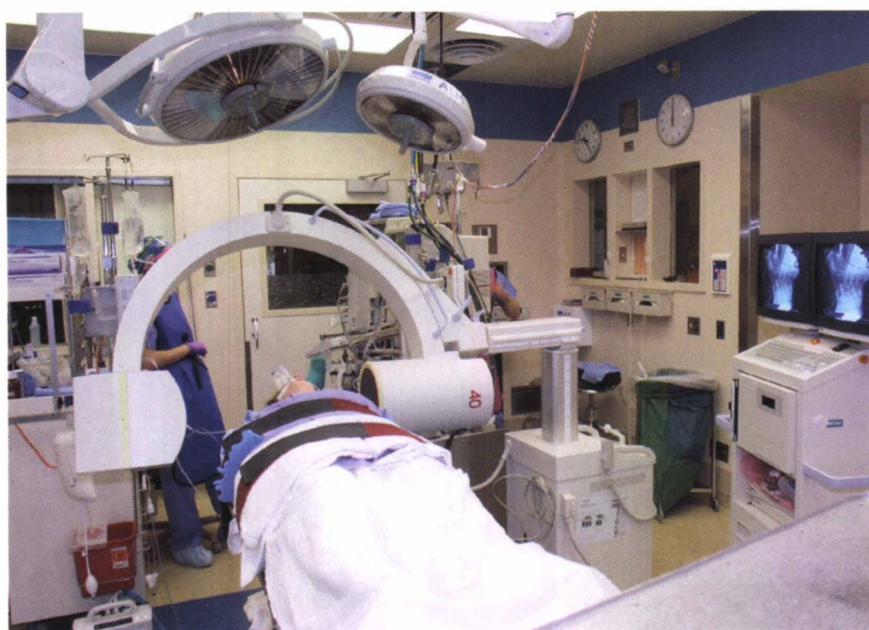
- Be certain there are no obstacles under the table that impedes movement of the C-arm.
- The C-arm often is positioned before the patient is draped. In this case the surgical team drapes the C-arm into the sterile field. Make sure the C-arm can be moved out of the way without disturbing any instrumentation.

### Structures shown

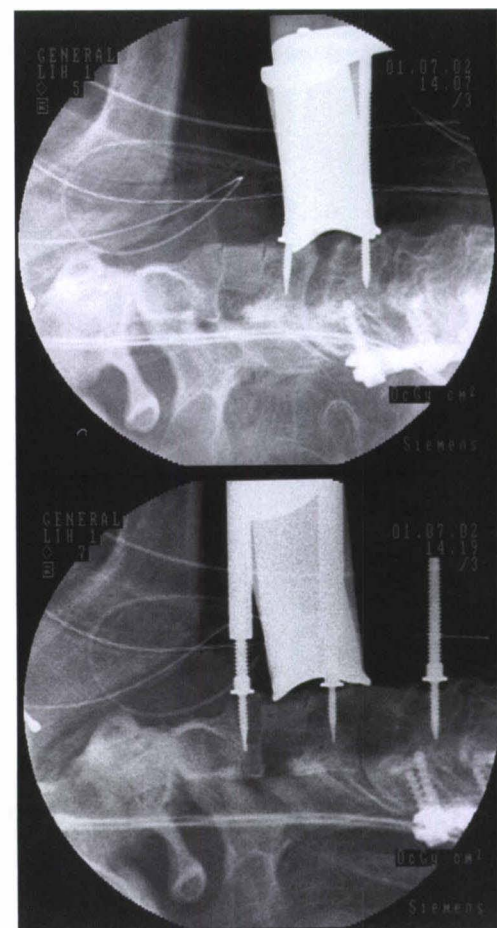
These positions show the affected area of the C-spine, as well as any hardware that may be introduced (Fig. 31-13). Since this surgery is most often performed to repair physiological defects, abnormalities such as osteophytes, degenerated disk spaces, or subluxation may be visible, especially in the lateral view.

### EVALUATION CRITERIA

- C-spine and its affected part in the center of the monitor to maintain proper radiographic technique.
- Image rotated in the same plane as patient.
- PA view should show spinous processes in the center of spinous bodies.
- Lateral view should show the bodies in profile and the interarticular facets lined up.
- Sterile field is maintained.



**Fig. 31-12** C-arm correctly placed in "rainbow" position for cervical procedures. Note images on monitor to the right.



**Fig. 31-13** Fluoroscopic image of cervical spine in lateral projection showing plate and screws used to fuse two vertebrae.

## LUMBAR SPINE

### Position of patient

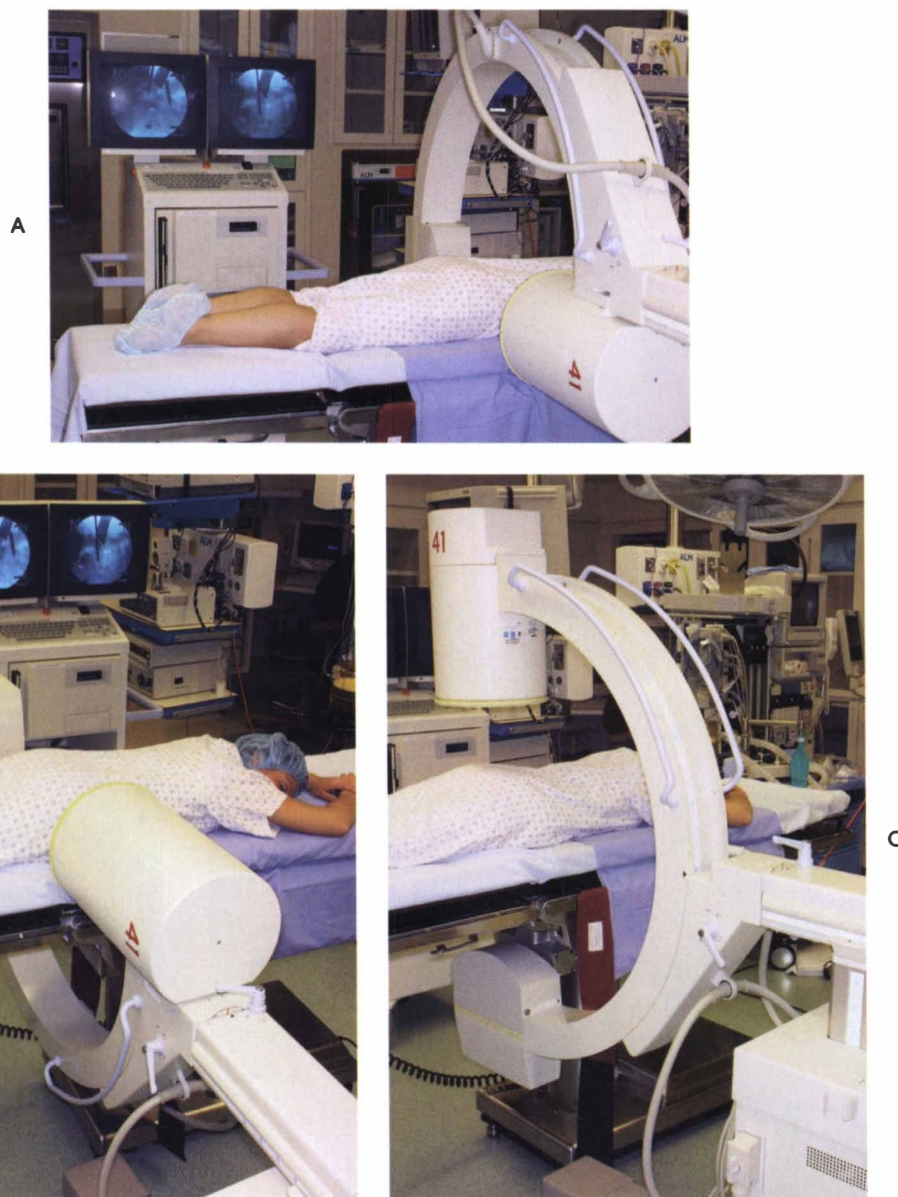
Patient is prone and positioned on chest rolls or a frame to flex the spine. Arms are placed on arm boards and located by the head of the table to bring them out of the field of view.

### Position of C-arm

#### AP Projection

Cover the C-arm with a sterile drape. The C-arm enters the field perpendicular to the patient. Center the beam in the AP projection over the affected area of the spine. Raise the C-arm to leave enough room between the IR and the patient so that the surgeon can work without being obstructed (Fig 31-14).

- Be certain there is nothing in or under the table to impair view of spine.



**Fig. 31-14** **A**, C-arm correctly placed in the rainbow position for lateral lumbar procedures. The rainbow position is used especially for larger patients in which the table or size of the patient would not allow enough elevation of the C-arm to include the lumbar spine. **B**, C-arm positioned under the table. **C**, C-arm positioned for AP projection of the lumbar spine.



### Lateral projection

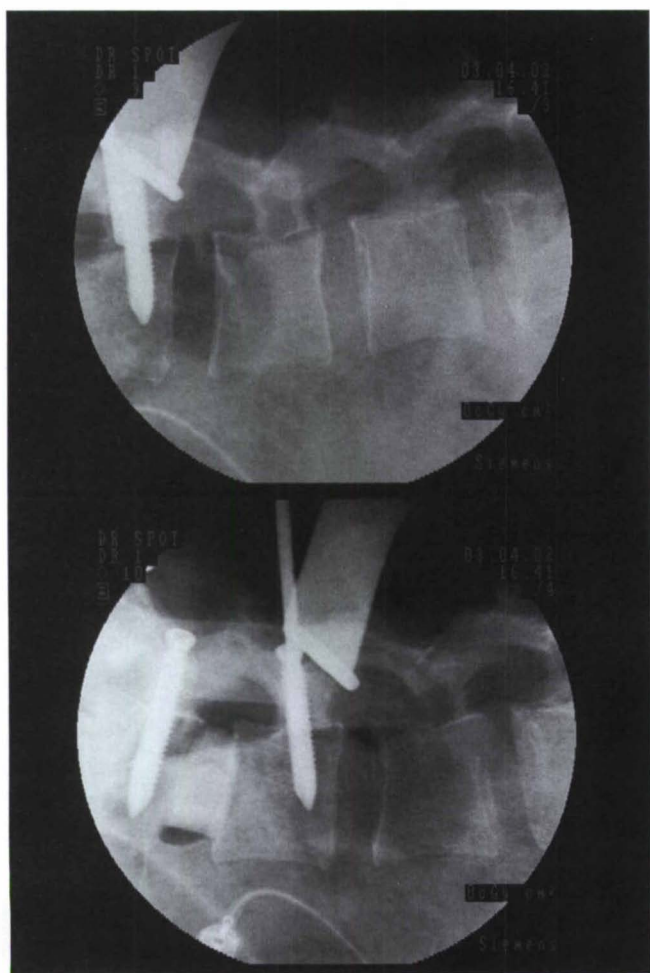
- Rotate the C-arm under the table into lateral position. Raise or lower the C-arm to bring the spine into the center of the monitor. The C-arm may need to be angled cephalad or caudal to obtain true lateral view. Rotate the image on the monitor until the image is in same plane as the patient. The C-arm may be arced over the patient for the lateral projection especially on hypersthenic patients in which rotating the C-arm under the table would not allow a great enough height to visualize the lumbar region.
- The surgical team will place sterile drapes over both ends of the C-arm when they drape the patient.

### Structures shown

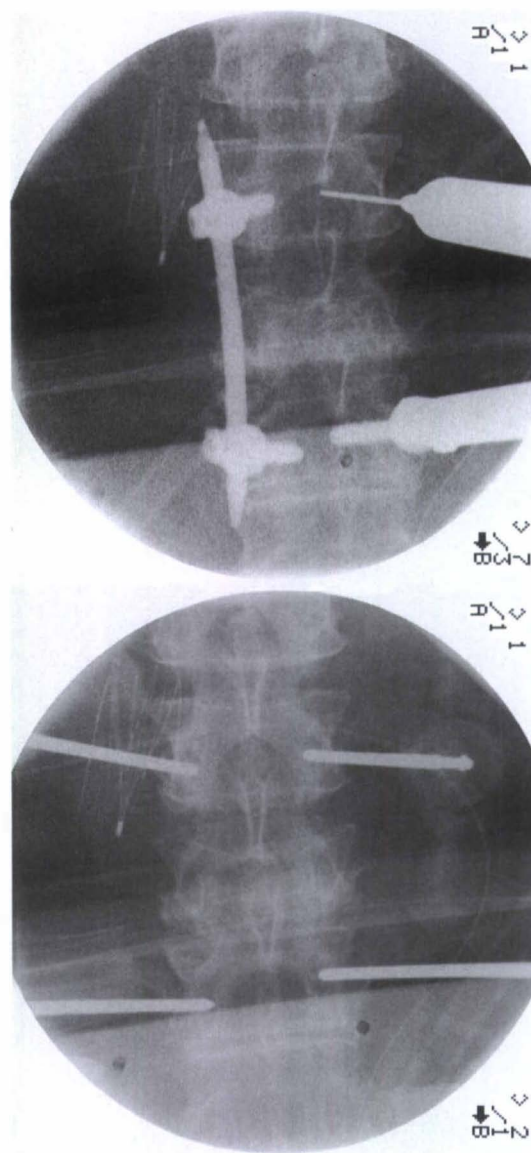
These projections show the affected area of the spine, which includes the bodies, disk spaces, spinous processes, lamina, pedicles, and facets. When the case is completed there will be hardware in the spine such as rods, plates, and screws to hold the spine in alignment. There may also be a bone graft or interbody fusion device in the disk space to fuse the bones together (Fig. 31-15).

### EVALUATION CRITERIA

- The affected area of the spine is viewed in its entirety (Fig. 31-16).
- The spine image is not rotated or angled on the monitor showing true AP and lateral views.
- Radiographic technique is maintained by properly centering the beam over the affected area.
- The image of the spine, whether AP or lateral, is rotated into the same plane as the patient. AP projection of spine is in vertical axis and lateral view of spine is in horizontal axis.
- Sterile field is maintained.
- Radiation protection is provided for surgical team.



**Fig. 31-15** Fluoroscopic hard copy lateral projection image of the lumbar spine with instrumentation.



**Fig. 31-16** AP projection fluoroscopic images during laparoscopic lumbar fusion.



## HIP (CANNULATED HIP SCREWS OR HIP PINNING)

### Position of Patient

Patient is supine with the legs abducted and the affected leg held in traction. The patient's arm on the affected side is crossed over the body to be kept out of the field of view.

- These procedures are often done using an isolation drape or "shower curtain." In these cases it is not necessary to cover the C-arm with a sterile drape; however, a non-sterile bag over the tube is recommended to prevent Betadine staining of the C-arm.
- The radiographer is positioned between the patient's legs so make sure the patient is covered completely to ensure privacy.

### Position of C-arm

Position the C-arm between the patient's legs and center the beam over the affected hip (Fig. 31-17). To obtain the lateral view, rotate the C-arm under the leg and table to lateral position (Fig. 31-18). Do not dislodge any instrumentation when rotating the C-arm.

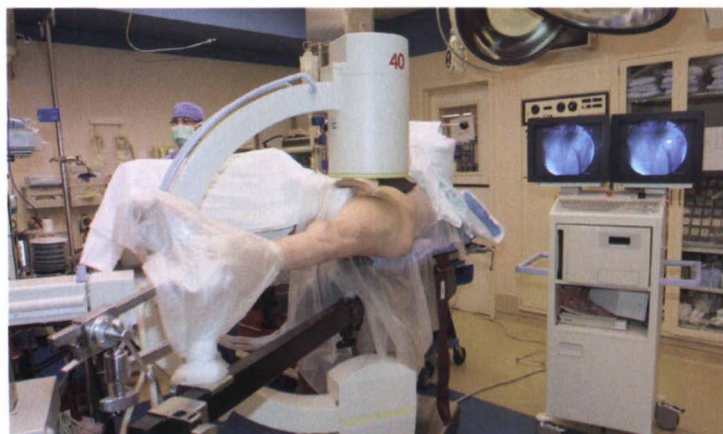


Fig. 31-17 C-arm positioned for PA projection of the hip.

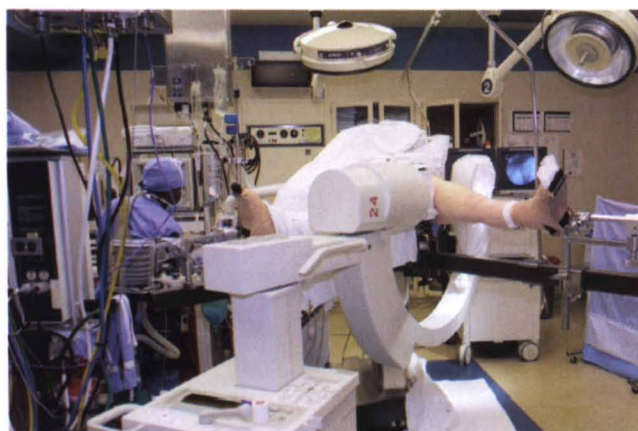


Fig. 31-18 C-arm properly positioned for lateral projection of the hip.

- Before the procedure the surgeon will manipulate the leg under fluoroscopy to reduce the fracture (Fig. 31-19).
- The C-arm may have to be manipulated to achieve views and may not be in true PA or lateral position. Note the position of the C-arm on PA and lateral views to return to this angle when needed.
- When hardware is in the hip, rotate the C-arm under fluoroscopy to ensure that no hardware is in the hip joint space.

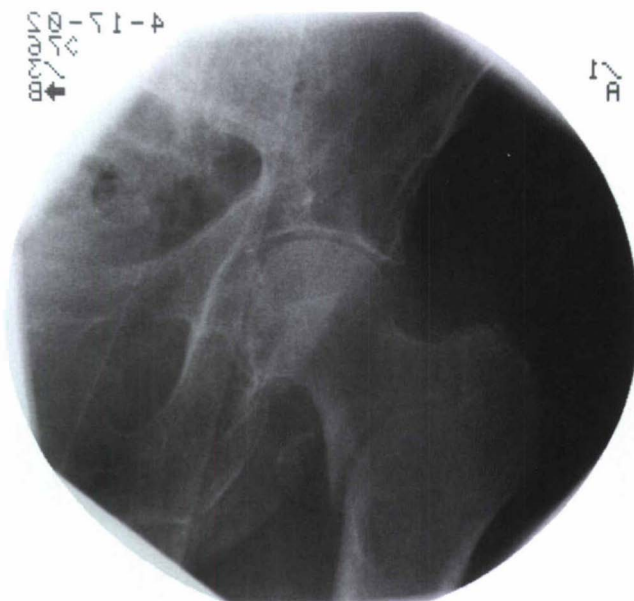


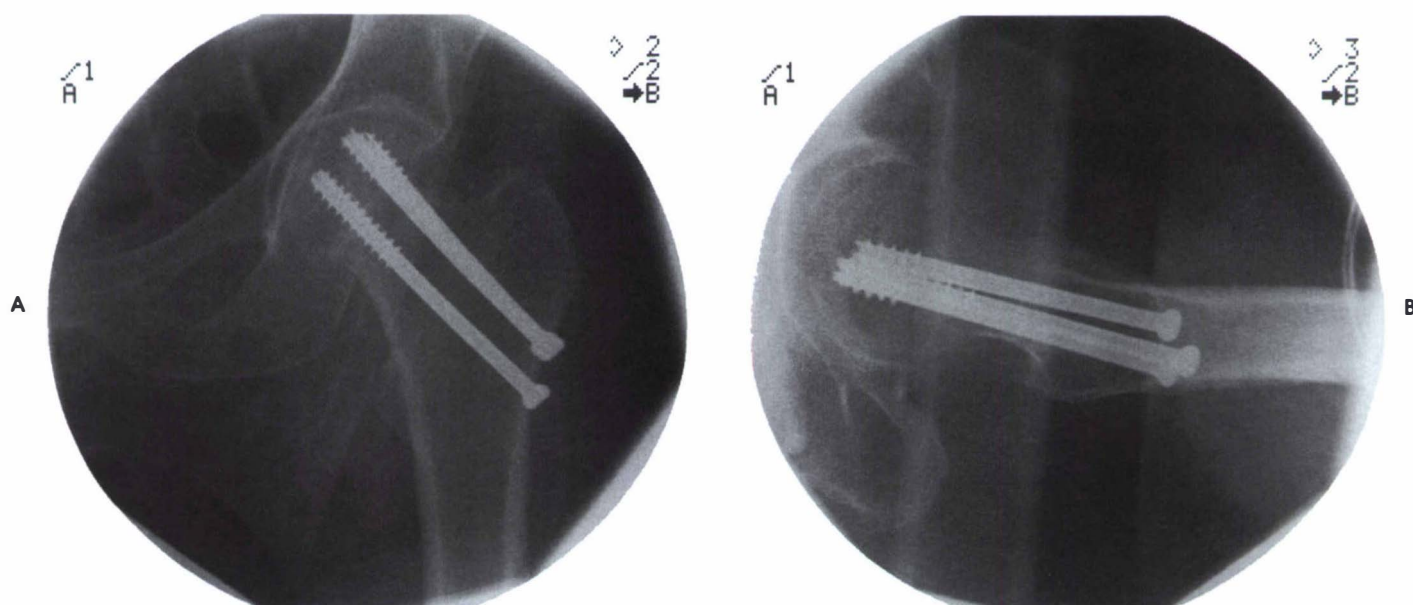
Fig. 31-19 AP projection of the hip with fracture of the femoral neck.

**Structures shown**

This examination shows all parts of proximal femur and hip joint, which includes the acetabular rim, the femoral head and neck, and the greater and lesser trochanters. Hardware may include cannulated screws or pins running parallel with the femoral neck used to reduce the fracture (Fig. 31-20).

**EVALUATION CRITERIA**

- Hip is centered on monitor and in correct plane.
- Lateral side of femur and acetabular rim must be visualized to determine a starting point and to ensure no hardware enters the joint.
- Lesser trochanter visible in profile on AP view. Greater trochanter lies behind the femoral neck and shaft in lateral view.
- Proper radiographic technique is maintained.
- Sterile field is maintained.
- Radiation protection provided.



**Fig. 31-20** AP projection **(A)** and lateral projection **(B)**. Fluoroscopic hard copy images of a hip fracture reduction.



## FEMUR NAIL

### Position of patient and C-arm

During this procedure a rod is inserted into the intramedullary (IM) canal to reduce a fracture of the shaft of the femur (Fig. 31-21). This rod or nail can be introduced either antegrade through the greater trochanter or retrograde through the popliteal notch.

### Antegrade femoral nailing

During antegrade nailing the patient is either supine or in the lateral position. In the supine position the affected leg will most likely be in traction to help reduce the fracture. The legs will be abducted and the unaffected leg will be flexed at the knee and hip and raised to allow the C-arm room to enter the sterile field. The patient's arm on the injured side is draped across the chest to keep it from obstructing the surgeon. With the patient in lateral position the affected leg is extended forward to clear the opposite leg. If the patient is supine, the C-arm is positioned between the patient's legs, parallel to the unaffected leg, and centered over the hip. The C-arm may have to be rotated forward or back to obtain a true PA projection. Rotate the C-arm under the table for lateral position.

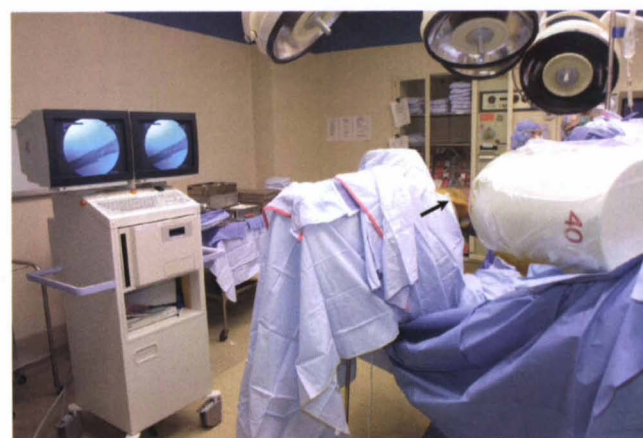
Antegrade with the patient in the lateral position requires the radiographer to enter the sterile field and rotate the C-arm under the table to find PA view of femur. Lateral position is achieved with the tube starting in a true PA position and rotating the C-arm forward 10 to 15 degrees and tilting it 5 to 10 degrees cephalad.



**Fig. 31-21** Image of a midshaft femoral fracture. Note the guide rod that is being inserted to align the fracture.



A



B

**Fig. 31-22 A**, C-arm positioned between patients legs for an PA projection during femoral nailing. Arrow is pointing to the femur. **B**, C-arm rotated under femur (arrow) for a lateral projection.

### Retrograde femoral nailing

During the retrograde femoral nailing, the patient is supine with the injured leg exposed and the knee flexed and supported with a bump. This position allows the surgeon access to the popliteal notch without injuring the patella.

The sterile field is entered with the C-arm perpendicular to the patient. Tilt the C-arm cephalad to account for the flexed knee and to find AP position. The C-arm is rotated under the table for lateral position (Fig. 31-22).

### Method

- There may be instruments or hardware protruding from the operation site. Be certain to keep from disturbing or allowing them to puncture sterile drape.
- Center the C-arm over the fracture sight during canal reaming to ensure the fracture remains reduced (Fig. 31-23).
- Table must allow for movement of the C-arm from the knee to the hip.
- Allow enough room between patient and C-arm for the surgeon to work.

Screws will be inserted into the femur and through the nail to fix the nail in place. When lining up the screw holes in the nail, the hole should be perfectly round and not oblong. Center the screw hole on the monitor. The magnification feature may be used to give the surgeon a better view. The C-arm may need to be tilted or rotated to obtain perfect circles. The surgeon will also manipulate the leg to help align the screw holes. Once the screws are inserted, check the length of the screws by placing the C-arm in AP position. Screws should not protrude excessively from the cortical bone (Fig. 31-24).

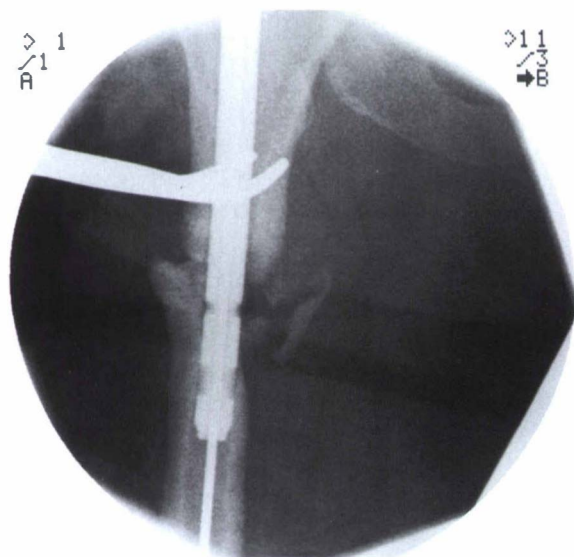


Fig. 31-23 Image of femur fracture during canal reaming.

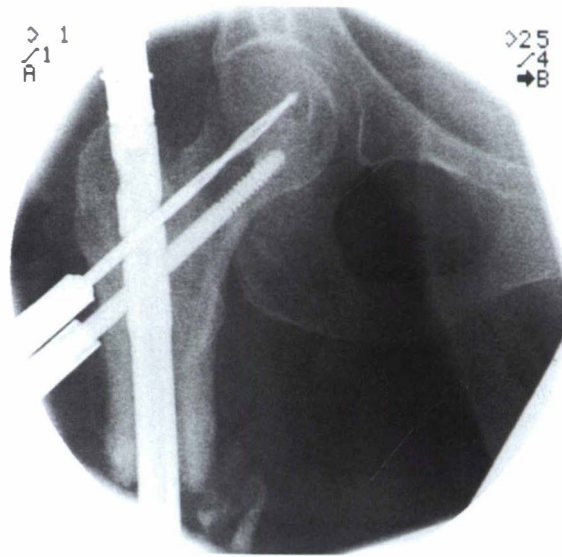


Fig. 31-24 AP projection of proximal screw in a femoral nail.

**Structures shown**

All parts of the femur including the greater and lesser trochanters, the femoral neck, shaft, and condyles are seen in the AP and lateral positions. There will be different instrumentation in the IM canal beginning with a guide rod that is used to help reduce the fracture and provide a means for the canal reamers to pass through the fracture site (Fig. 31-25). After reduction, the nail and screws are seen.

**EVALUATION CRITERIA**

- Appropriate views are seen unobstructed and in correct plane on the monitor.
- Screw holes are perfectly round and in the center of the monitor.
- Sterile field is maintained.
- Proper radiographic technique is maintained
- Radiation protection provided for surgical team.



**Fig. 31-25** AP projection of a femur fracture reduced with guide rod and distal interlocking screws inserted.



## TIBIA (NAIL)

### Position of patient

Patient is supine with the affected leg exposed. The knee is flexed to allow access to the tibial tuberosity without injuring the patella. The injured leg is on the opposite side of the table so that the C-arm does not interfere with the surgical team.

### Position of C-arm

Cover the C-arm with a sterile drape. Move the C-arm into the field perpendicular to the patient. Center the beam over the leg and tilt the tube to match the angle of the leg (Fig. 31-26). There should not be any obstructions under the table that will interfere with the C-arm movement. Rotate the C-arm under the table and into the lateral position making certain not to disturb any instrumentation protruding from the operative site. Center the leg on the monitor by raising or lowering the C-arm. The surgeon will manipulate the leg and the radiographer will tilt or rotate the C-arm to obtain round holes (Figs. 31-27 and 31-28). Use the magnification feature to enlarge the im-

age if needed. Advance the C-arm until the tube side of the C-arm is far enough from the injured leg to allow the surgeon to fit the drill and drill bit into the area.

- Along its shaft the tibia is triangular shaped so when checking the length of the screws the C-arm may have to be rotated forward or back to get true length.
- Center the beam on the fracture site during canal reaming. Once the leg is in the center of the monitor, turn the wheels of the C-arm horizontally to allow the machine to move longitudinally down the shaft of the leg without moving out of the field of view.



**Fig. 31-26** C-arm positioned for tibial nailing. Note radiographer positioned the fluoroscopic image intensifier to be parallel with the long axis of the leg.



**Fig. 31-27** Image of tibial nail screw holes in incorrect alignment and oblong in shape.



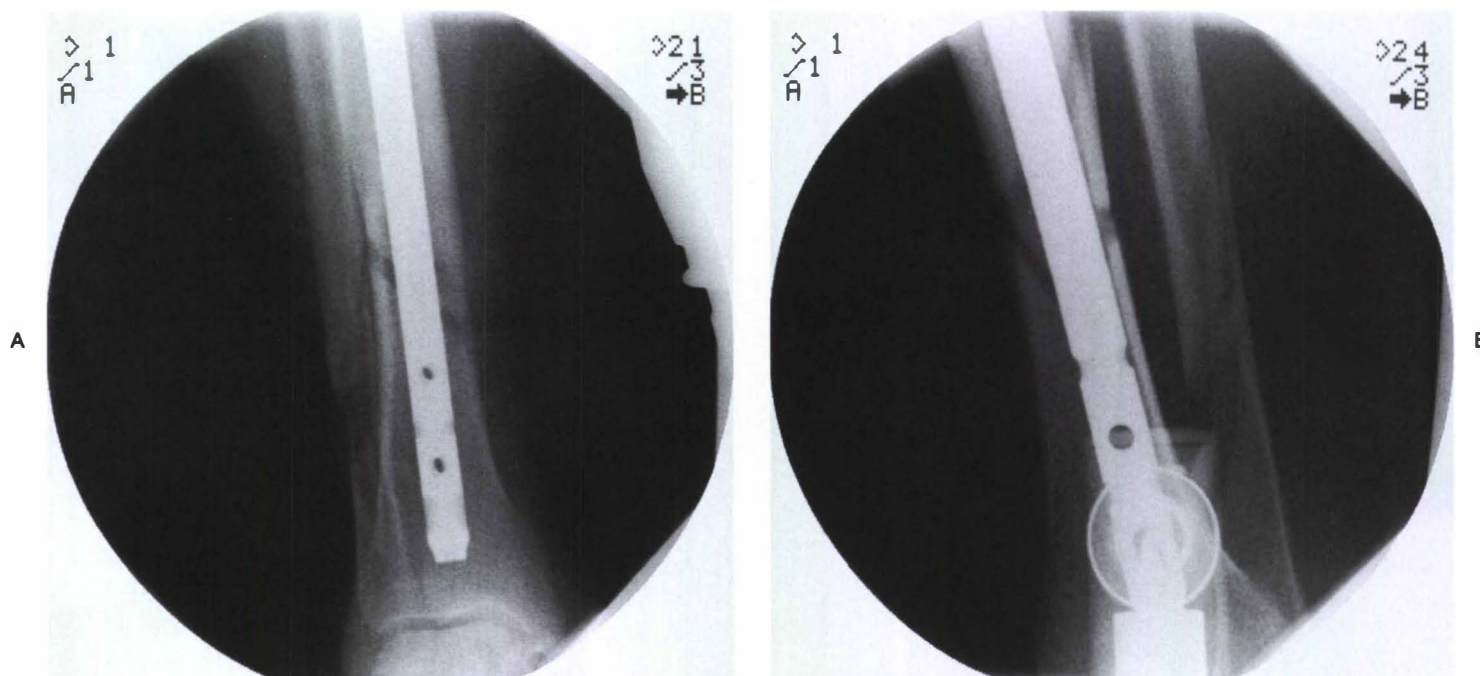
**Fig. 31-28** Image of tibial nail screw holes perfectly round, and magnified to assist proper alignment.

**Structures shown**

The tibia and fibula, the tibial shaft along with any fracture, tibial plateau, tibial tuberosity, the distal tibia, and ankle joint (Fig. 31-29). After hardware is inserted the tibial nail will fill the IM canal with proximal and distal screws prominent.

**EVALUATION CRITERIA**

- The tibia is centered on the monitor providing proper radiographic technique.
- Appropriate views are seen unobstructed and in the correct plane on monitor.
- Sterile field is maintained.
- Radiation protection provided for surgical team.



**Fig. 31-29** **A**, Improper alignment of distal screw holes. **B**, Screw holes properly aligned with screw driver over distal screw hole.

## HUMERUS

### Position of patient

Patient is supine, or in a reclining or beach chair position (Fig. 31-30). The injured arm may be resting on a mayo stand with the surgeon's assistant holding the arm to stabilize and align the humerus. The patient should be positioned with the shoulder off the side of the table. This position allows the humerus to be seen in its entirety without being obscured by the table.

### Position of C-arm

Cover the C-arm with a sterile drape. Enter the field perpendicular or at a 45 degree angle to the patient. The assistant will rotate the arm medially with the elbow bent 90 degrees. The C-arm is tilted and rotated to obtain a true lateral view depending on the angle of patient position. The arm is held at the elbow to provide support and the arm is rotated until the hand is pointing up. The C-arm is tilted to obtain PA projection according to patient angle. Center the beam on the humerus.

- When installing a nail or rod into the humerus and trying to locate and center the distal screws, place a sterile drape over the tube or pull the sheets draping the patient over the tube. Only touch the underside of the sheets when placing them over the tube. Raise the tube to magnify the screw holes and to allow the surgeon to work.



Fig. 31-30 C-arm positioned for patient in beach chair position.





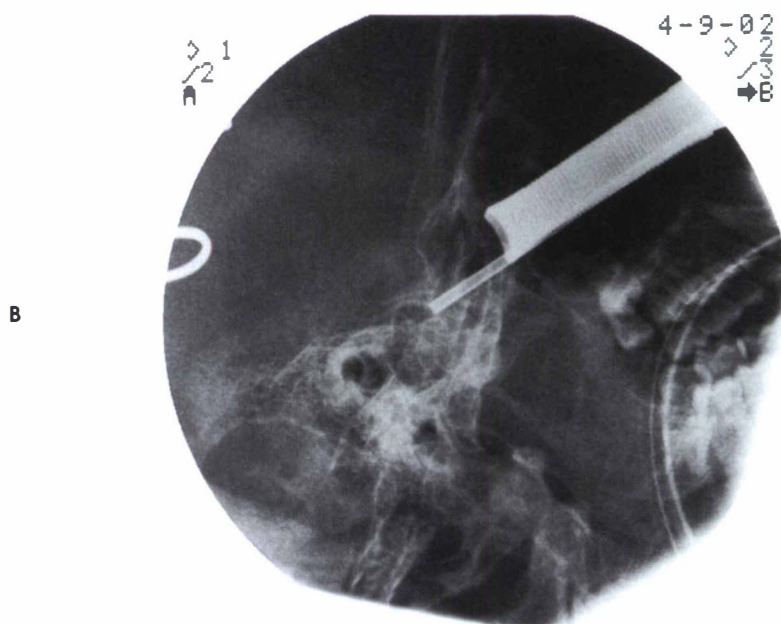
## TRANSSPHENOIDAL RESECTION OF PITUITARY TUMOR

### Position of patient

Patient is supine with the arms down at the sides. The head will either be on the table or off the end of the table and held in a halo. The head will be tilted toward the surgical team slightly and the chin will be extended upward.

### Position of C-arm

The C-arm is placed into position before the procedure begins. The C-arm will enter perpendicular to the patient. Rotate the tube into the lateral position. Tilt and rotate the C-arm to obtain true lateral position. Center the beam on the temporal bone to put the sella turcica in the middle of the monitor. X-ray tube should be positioned closer to the skull to magnify the view of the pituitary region. Lock the machine in place (Fig. 31-32). The C-arm is seen during the actual procedure in Fig. 31-33.



**Fig. 31-32 A,** C-arm positioned for transsphenoidal tumor removal. **B,** Transsphenoidal tumor removal with scope in place.

**Structures shown**

The skull is shown in lateral view with concentration on the area of the pituitary gland. The sella turcica, the base of the skull, the orbits, maxillary sinuses, and portions of the C-spine and mandible are also seen.

**EVALUATION CRITERIA**

- True lateral view of the skull with the sella turcica in the center of the monitor.
- Orbits, sphenoid wings, and maxillary sinuses superimposed.
- Proper radiographic technique maintained.
- Surgical team should maintain sterile field when the machine is draped into the sterile field.
- Image of the skull should be in the same plane as patient.



**Fig. 31-33** C-arm sterile draped and positioned for transsphenoidal tumor removal. Patient's head indicated by arrow.

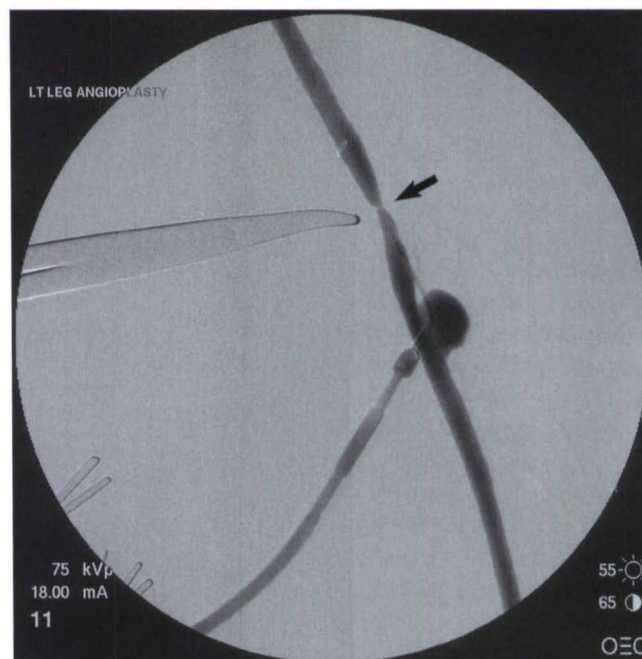


**FEMORAL/ TIBIAL ARTERIOGRAM****Position of patient**

Patient is supine with the affected leg exposed from the groin area to the foot. There should be enough room under the table to allow the C-arm to move from the hip to the foot. Leg may be rotated medially or laterally to keep the femur or tibia from obscuring any vasculature (Fig. 31-34).

**Position of C-arm**

Cover the C-arm with a sterile drape and enter the field perpendicular to the patient. Once the leg is in the center of the monitor, turn the wheels of the C-arm horizontally to allow the machine to move to the left or right without taking the leg out of the field of view. Use the subtraction or road-mapping feature to remove all structures except the contrast that is injected into the artery (Fig. 31-35). This feature shows any stenoses or injuries to the artery.



**Fig. 31-34** Subtraction image of a surgical femoral artery angiogram with stenosis (arrow).

**Structures shown**

The bones of the leg are seen before subtraction. After contrast is introduced the femoral artery and its branches are seen and following the contrast down the leg the popliteal and tibial arteries is seen. The contrast images show any pathological defects in the arterial structures.

**EVALUATION CRITERIA**

- All pertinent vasculature must be shown without being obscured by the table or bones of the leg.
- The integrity of the mask image should be maintained by not moving the leg or the C-arm during subtraction or road mapping.
- Proper radiographic technique is maintained.
- Sterile field is maintained.
- Radiation protection provided for surgical team.



**Fig. 31-35** Subtraction image of a surgical femoral artery angiogram after balloon angioplasty.

## Mobile Radiography Procedures For The Operating Room

### CERVICAL SPINE

**Image receptor:** 10 × 12 inch grid IR crosswise.

#### Position of patient

Patient is upright, prone, or supine. In the upright and prone positions the patient's head is held in a traction device to align the spine. In the supine position the chin is elevated and held with a strap or tape.

#### Position of IR and portable machine

(Fig. 31-36)

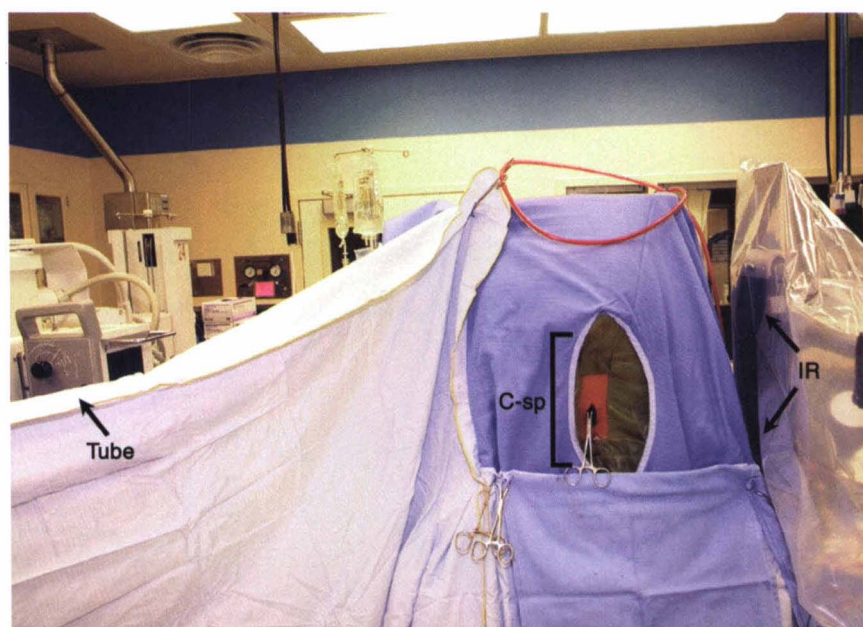
- Place grid IR in the IR holder and cover with a sterile drape.
- Position IR holder on opposite side of patient. The surgical tech will move the sterile back table so that the radiographer does not compromise the sterile field.
- Direct the beam perpendicular to the IR and parallel to the floor.
- Beam enters perpendicular to the IR to eliminate grid cut-off.
- Raise or lower the tube and IR to center on the c-spine.

#### Structures shown

- Cervical spine in lateral projection (Fig. 31-37).
- Degenerative or pathological defects such as osteophytes, fractures, or subluxation.
- Radiograph may be taken at the beginning of the case to verify the correct portion of spine to be repaired. There will be instruments placed to designate the level of the spine (Fig. 31-38).

#### EVALUATION CRITERIA

- Entire spine on the radiograph.
- Spine is in the center of the radiograph and is not rotated.
- Proper radiographic technique used.
- Radiation protection provided for surgical team.
- All hardware that may be used should be included.
- Absence of grid cut-off.



**Fig. 31-36** Mobile radiographic machine (arrow) in position for an upright lateral cervical spine. Note the surgical clamp, which is attached to the spinous process of interest, extending from the incision site. Note the IR draped and in holder (double arrows).





**Fig. 31-37** Lateral cervical spine radiograph (patient in sitting position for surgery) showing a localization marker in place on the spinous process of C-6.



**Fig. 31-38** Lateral projection of the cervical spine with patient supine. Done to verify the correct position of instruments before continuing surgery. Often a spinal needle is placed in the disc space to show position.

## THORACIC OR LUMBAR SPINE

**Image receptor:** 35 × 43 cm grid IR crosswise

### Position of patient

Patient is prone or supine with the arms placed up by the head. The chest and abdomen are supported by a frame or chest roll to flex the spine into anatomic position.

- Radiograph may be done to verify that the surgeon is working on the correct vertebra or to show the position of hardware (Fig. 31-39).

### Lateral view

Place grid IR in IR holder and cover with a sterile drape. Position the holder next to the patient and move the IR up or down to center on the lumbar spine. Direct the beam perpendicular to the IR and parallel to the floor (Fig. 31-40). Respiration should be suspended during exposure.

### PA view

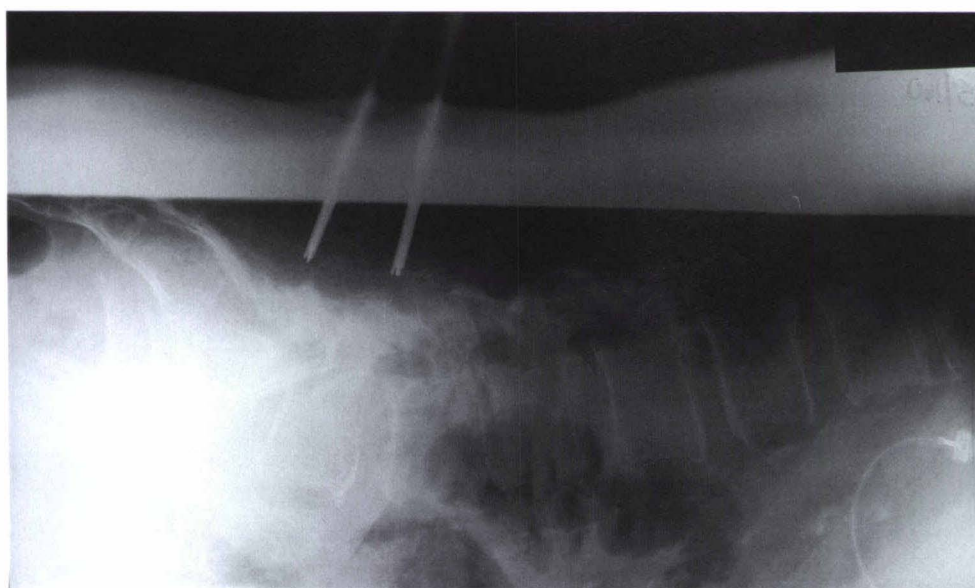
For the PA radiograph, slide film in the slot under the table and center on the spine. Cover field with sterile drape. Center the beam to the IR and perpendicular to the long axis of the spine.

### Structures shown

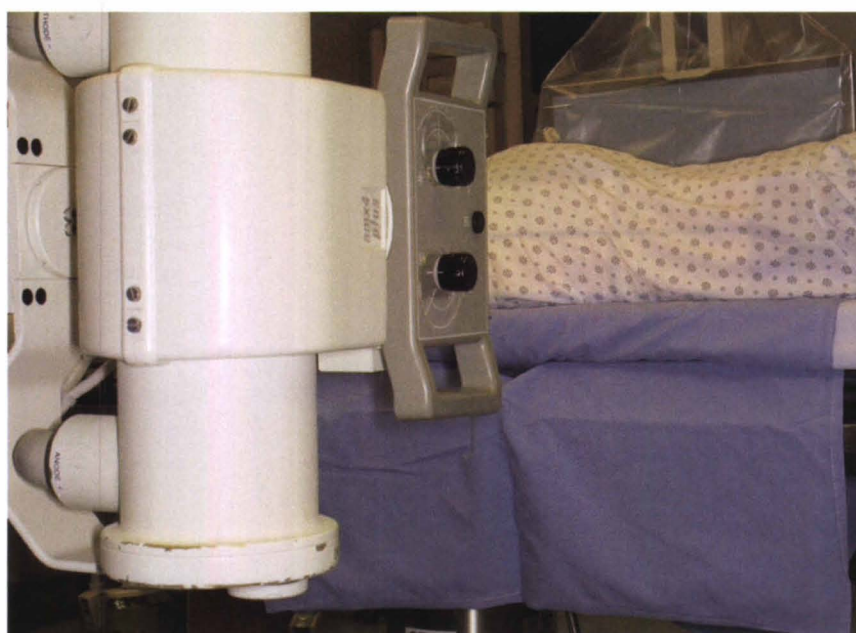
- The lumbar spine in PA and lateral views.
- Vertebral bodies, spinous processes, facets, and lamina.
- Hardware to repair any defects. Bone grafts or interbody fusion devices may be used.
- Instrumentation is often seen on radiograph.
- PA view may be obscured by the patient support.

### EVALUATION CRITERIA

- Spine is in the center of the radiograph and in true PA or lateral position.
- Spine bodies seen without any rotation.
- All hardware used must be seen on radiograph.
- All unnecessary instrumentation removed to keep from obscuring spine.
- Proper radiographic technique used.
- Radiation protection provided for surgical team.



**Fig. 31-39** Lateral projection of the lumbar spine with instrumentation placed at L-5 to verify the correct level of vertebra of interest. Note the patient is prone.



A



B

**Fig. 31-40** **A**, Mobile x-ray machine correctly positioned for cross-table lateral lumbar spine. **B**, Radiographer positioning mobile unit intraoperatively for lateral lumbar spine procedure.





Fig. 31-41 AP projection of the hip with joint replacement.



Fig. 31-42 AP projection of the knee, in immobilizer, with joint replacement.

## EXTREMITY EXAMINATIONS

**Image receptor:** Choose the appropriate size IR to include all appropriate anatomy and hardware.

### Position of patient

Patient is supine, prone, reclining, or in the beach chair position.

Portable machines approach perpendicular to the patient. Some institutions may cover the tube with a sterile drape; others may cover the sterile field with a drape, or both. Angle the tube to match the IR or desired projection. The surgeon may choose to hold the patient's limb in position during the exposure. To reduce exposure to the surgeon, positioning aides such as sterile towels, sponges, or mallets may be used.



Fig. 31-43 AP projection of the ankle with plate and screw fixation.

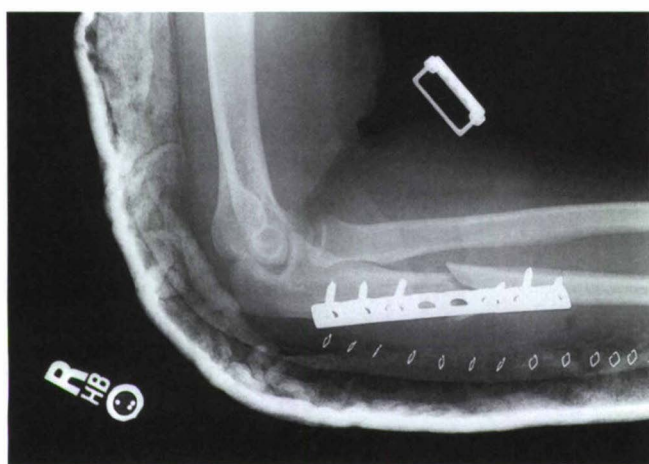
The surgeon may also cover the field with a cloth sterile drape rather than a plastic sterile drape. If so, the surgeon will mark the location of the part to ensure proper centering. Lighting may also need to be adjusted for better visualization of the field. For cross-table examinations the beam is directed perpendicular to the film and parallel to the floor. Center the beam to the IR and raise or lower the tube to the center of the part.

#### Structures shown

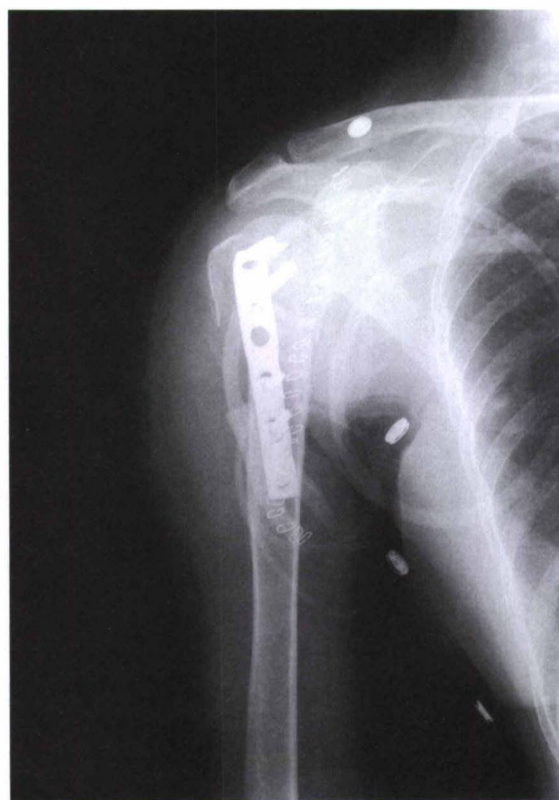
- All pertinent anatomy in correct alignment.
- Hardware including plates, wires, pins, screws, external fixation, and joint replacement components used to repair fractures or degenerative problems (Figs. 31-41, 31-42, 31-43, 31-44, 31-45, and 31-46).



**Fig. 31-44** AP projection of proximal tibia with a plate and screw fixation used to repair a tibial plateau fracture.



**Fig. 31-45** Lateral projection of the elbow with plate and screws used to reduce a forearm fracture.



**Fig. 31-46** Internal rotation projection of the shoulder with a plate and screws. Creative patient positioning or tube angulation may be necessary to achieve optimal images on complex comminuted fractures.

**EVALUATION CRITERIA**

- Complete joint including all hardware is seen on the film.
- Proper radiographic technique is used.
- Sterile field is maintained.
- Radiation protection provided for surgical team.
- Collimation to include all hardware used.
- No unnecessary instruments in field.

**NOTE:** Often to save time or cost, multiple views are done on one imaging plate. Be careful not to superimpose any of the views. Many surgeons will request different projections depending on the individual case. For example, when performing a wrist examination, the arm is positioned on one side of the film with the wrist in the AP or PA position. Center the beam and collimate to the wrist to include all hardware. Once the exposure is complete, the surgeon will move the arm to the other side of the film in the lateral position. Center the beam on the wrist and collimate (Fig. 31-47).



**Fig. 31-47** **A**, Radiographer positioning mobile machine for a lateral projection of the wrist. **B**, AP and lateral projections of the wrist on 24 × 30 cm IR. Note fracture of the navicular with fixation screw in place.



## Definition of Terms

**antisepsis** The chemical disinfection of the skin.

**asepsis** The absence of infection, germs, or elimination of infectious agents.

**aseptic technique** Principles involved with manipulation of sterile and unsterile items to prevent or minimize microbiologic contamination.

**contamination** The presence of pathogenic microorganisms.

**microbial fallout** Microorganisms normally shed from skin that can contaminate sterile surfaces or areas.

**restricted area** Operating rooms, clean core or sterile storage areas.

**semi-restricted area** Area of peripheral support, such as hallways or corridors leading to restricted areas.

**sterile** A substance or object that is completely free of living microorganisms and is incapable of producing any form of organism.

**strike-through** Soaking through of moisture from non-sterile surfaces to sterile surfaces, or vice versa, allowing transportation of bacteria to sterile areas.

**teamwork** The Association of Surgical Technologist's (AST) Standards of Practice Standard I states Teamwork is essential for perioperative patient care and is contingent on interpersonal skills. Communication is critical to the positive attainment of expected outcomes of care. All team members should work together for the common good of the patient. For the benefit of the patient and the delivery of actions with the health care team, the patient and family, superiors, and peers. Personal integrity and surgical conscience are integrated into every aspect of professional behavior.

**unrestricted area** Areas in which street clothes are permitted such as outer hallways, family waiting areas, locker rooms, employee lounges.

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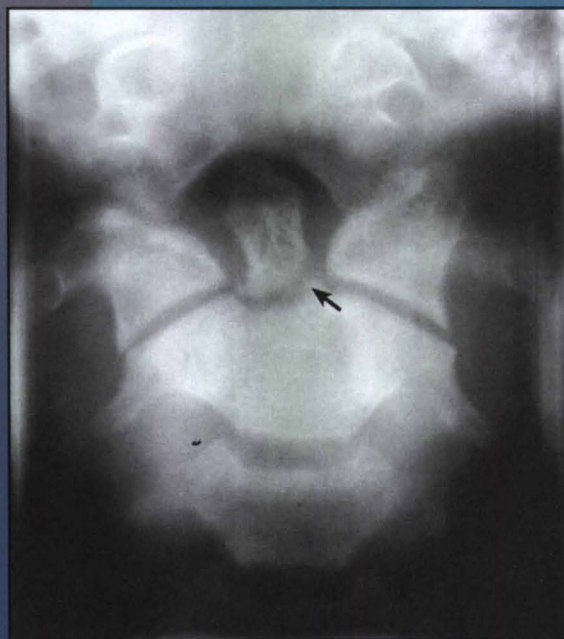
32

# TOMOGRAPHY

## OUTLINE

Historical development, 306  
Physical principles, 307  
Clinical applications, 308  
Basic principles  
    of positioning, 318  
Immobilization techniques, 319  
Scout tomograms, 319  
General rules  
    for tomography, 322  
Conclusion, 326  
Definition of terms, 327

AP tomogram of C1-C3 demonstrating complete fracture at base of dens (arrow).





## Historical Development

Since its inception in the 1890s, radiography has faced the problem of trying to record three-dimensional body structures accurately as two-dimensional images. This unavoidably results in the superimposition of structures, which often obscures important diagnostic information. One attempt to overcome this problem is the use of right-angle images. Over the years many other techniques have been developed that partially circumvent the problem of superimposition, such as multiple radiographs, stereoscopic images, and subtraction techniques in angiography.

The partial or complete elimination of obscuring shadows by the effect of motion on shadow formation is a common technique used in radiography. This effect is frequently used with conventional projections. For example, in conjunction with a long exposure time, breathing motion is used to reduce rib and pulmonary shadows to a background blur on frontal images of the sternum and lateral radiographs of the thoracic spine.

*Body-section radiography* (or more appropriately, *tomography*) is a term used to designate a radiographic technique by which most of the problems of superimposed images are overcome. *Tomography*<sup>\*</sup> is the term used to designate the technique whereby a predetermined plane of the body is demonstrated in focus on the radiograph. Other body structures above or below the plane of interest are eliminated from the image or are rendered as a low-density blur caused by motion.

<sup>\*</sup>Almost all italicized words on the succeeding pages are defined at the end of the chapter.

The origin of tomography cannot be attributed to any one person; in fact, tomography was developed by several different gifted individuals experimenting in different countries at about the same time without any knowledge of each other's work. In 1921 Dr. André-Edmund-Marie Bocage, a French dermatologist, described in an application for a patent many of the principles used in modern tomographic equipment. Many other early investigators made significant contributions to the field of tomography. Each of these pioneers applied a different name to a particular device or process of body-section radiography. Bocage (1922) termed the result of his process *moving film roentgenograms*; the Italian Vallebona (1930) chose the term *stratigraphy*; the Dutch physician Ziedes des Plantes (1932), who made several significant contributions, called his process *planigraphy*. The term *tomography* came from the German investigator Grossman, as does the *Grossman principle*, which is discussed later in this section.

Tomography was invented in the United States in 1928 by Jean Kieffer, a radiographer who developed the special radiographic technique to demonstrate a form of tuberculosis that he had. His process was termed *laminagraphy* by another American, J. Robert Andrews, who assisted Kieffer in the construction of his first tomographic device, the laminagraph.<sup>1</sup>

A great deal of confusion arose over the many different names given to the general process of body-section radiography. To eliminate this confusion, the International Commission of Radiological Units and Standards appointed a committee in 1962 to select a single term to represent all of the processes. *Tomography* is the term the committee chose, and this term is now recognized throughout the medical community as the single appropriate term for all forms of *body-section radiography*.<sup>2</sup>

<sup>1</sup>Littleton JT: *Tomography: physical principles and clinical applications*, Baltimore, 1976, Williams & Wilkins.

<sup>2</sup>Vallebona A, Bistolfi F: *Modern thin-section tomography*, Springfield, Ill, 1973, Charles C. Thomas.

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## Physical Principles

The physical principles of tomography are discussed in detail in all of the physics and imaging related textbooks. Since the primary purpose of the Atlas is to present radiographic positions, projections, and procedures, the physical principles previously discussed in this text have been removed. See the sixth, seventh, eighth, and ninth editions of this atlas for the previously contained physical principles.

## Clinical Applications

Tomography is a proven diagnostic tool that can be of significant value when a definitive diagnosis cannot be made from conventional radiographs. This is because tomography can remove confusing shadows from the point of interest. Tomography may be used in any part of the body but is most effective in areas of high contrast such as bone and lung. Body-section radiography is used to demonstrate and evaluate a number of different pathologic processes, traumatic injuries, and congenital abnormalities. A basic familiarization with the clinical applications of tomography helps the tomographer to be more effective. Some of the major clinical applications of tomography are described in the following sections. However this versatile technique has other applications as well.

### PATHOLOGIC PROCESSES IN SOFT TISSUES

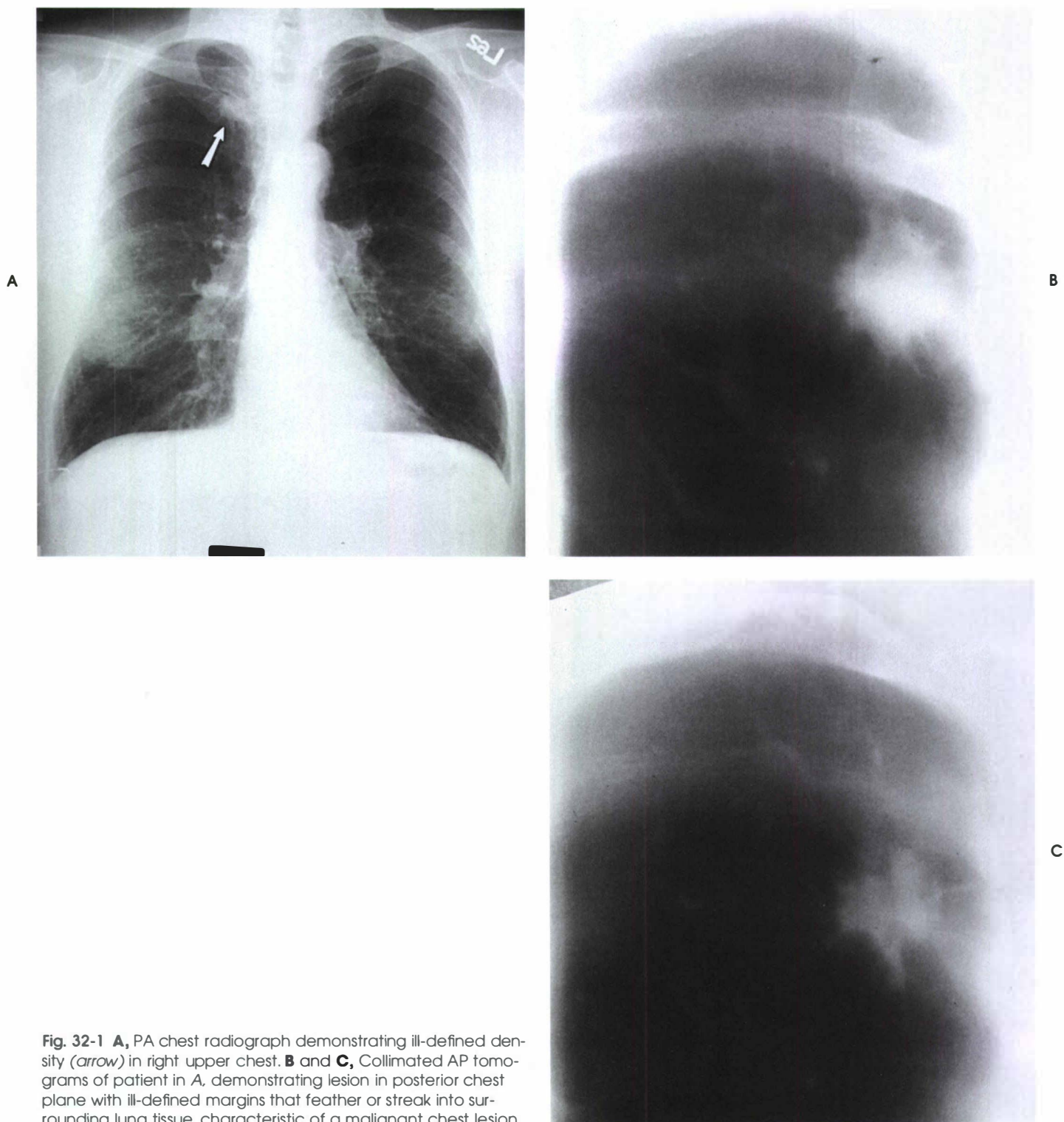
Tomography is frequently used to demonstrate and evaluate benign processes and malignant neoplasms in the lungs. Benign lesions and malignancies cannot always be differentiated with conventional chest radiography. However, tomography is capable of defining the location, size, shape, and marginal contours of a lesion.

Benign lesions characteristically have smooth, well-marginated contours and frequently contain bits of calcium. The presence of calcium in a chest lesion usually confirms it as being benign. The benign lesions most commonly found in the lungs are granulomas, which form as a tissue reaction to a chronic infectious process that has healed.

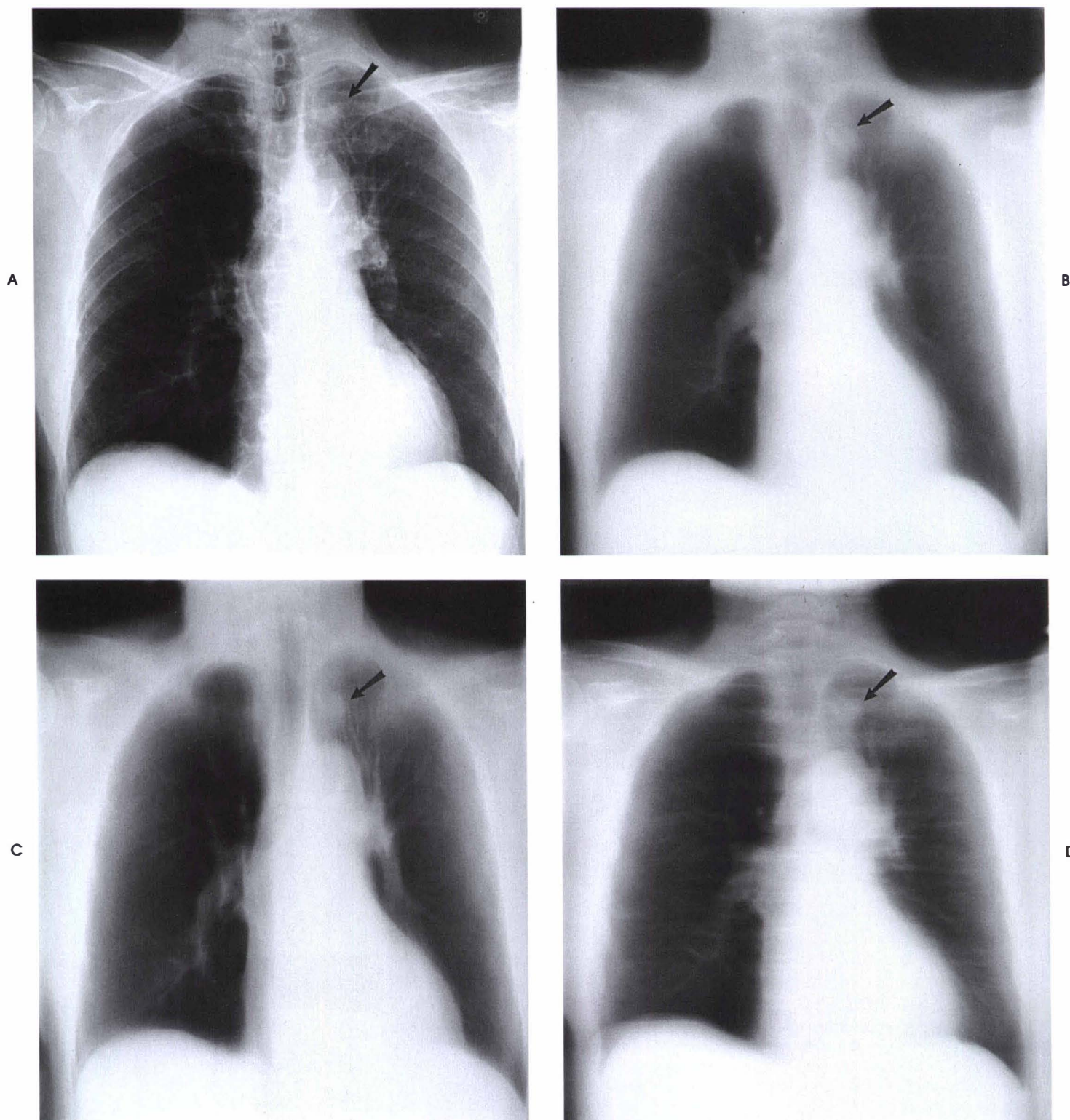
Conversely, carcinogenic neoplasms characteristically have ill-defined margins that feather or streak into the surrounding tissue and rarely contain calcium (Figs. 32-1 and 32-2). Lung cancers may originate in the lung, in which case the neoplasm is termed a primary malignancy. Bronchogenic carcinoma is an example of a *primary malignancy* that may develop in the chest. Lung cancers may develop as the result of the spread of cancer from another area of the body to the lungs. These malignancies are termed *secondary*, or *metastatic, tumors*. Breast cancer, testicular cancer, and other malignancies may metastasize to the lungs.

When an apparent solitary nodule is noted on a conventional chest radiograph, the presence or exclusion of other lesions may be determined with general tomographic surveys of both lungs. These “whole-lung” or “full-lung” tomograms are used to exclude the possibility of metastatic disease from other organs. Frequently these lesions cannot be visualized by conventional radiographic techniques, and tomography is one means to identify these occult nodules. Demonstration of the number of tumors and their location, size, and relationship to other pulmonary structures is crucial to the physician’s plan of treatment and the prognosis for the patient. Reexamination by tomography may be performed at a later date to check on the progress of the disease and the effectiveness of the therapy.





**Fig. 32-1** **A**, PA chest radiograph demonstrating ill-defined density (arrow) in right upper chest. **B** and **C**, Collimated AP tomograms of patient in **A**, demonstrating lesion in posterior chest plane with ill-defined margins that feather or streak into surrounding lung tissue, characteristic of a malignant chest lesion.



**Fig. 32-2** **A**, AP chest radiograph with vague density (*arrow*) over medial end of left clavicle. **B to D**, AP full-lung tomograms of patient in **A**, taken to exclude the possibility of other occult lesions. **B**, Trispiral tomogram  $\frac{3}{8}$  inch (1 cm) anterior to hilar plane at level of tumor. Radiographic appearance of lesion (*arrow*) is consistent with malignant chest neoplasm. **C**, Longitudinal linear tomogram of 40 degrees at same fulcrum level as **B**. Visualization of lesion (*arrow*) is decreased because of linear streaking and incomplete blurring of other structures outside the focal plane. **D**, A 40-degree transverse linear tomogram at the same level as **B** and **C**, again demonstrating poor visualization of lesion (*arrow*) because of linear blurring characteristics. Blurring of anterior ribs is incomplete.



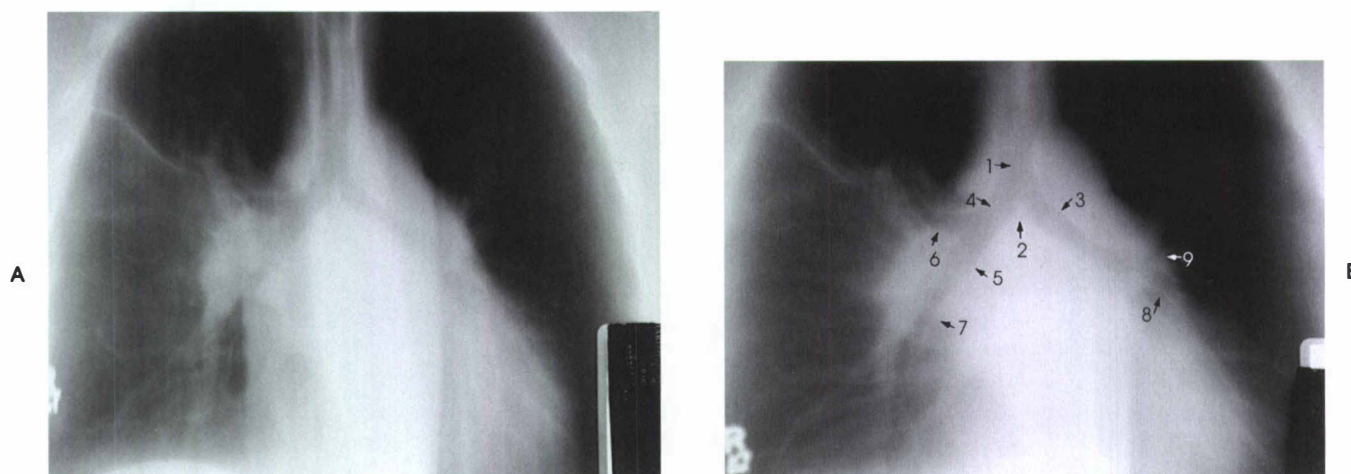
### PULMONARY HILA

Neoplasms involving the pulmonary hila are effectively evaluated by tomography, which can determine if and to what degree the individual bronchi are patent or obstructed. This partial or complete obstruction may occur when a neoplasm develops within the bronchus and bulges into the bronchial airspace when a tumor grows adjacent to the bronchus. As the lesion grows, it may press against the bronchus, reducing the size of the lumen and thus restricting or obstructing airflow to that part of the lung. Pneumonia, atelectasis, and other inflammatory or reactive changes that may occur with the obstruction may further hinder conventional imaging of this area. Demonstration of bronchial patency through a density is strong evidence that the lesion is inflammatory and not malignant (Fig. 32-3).

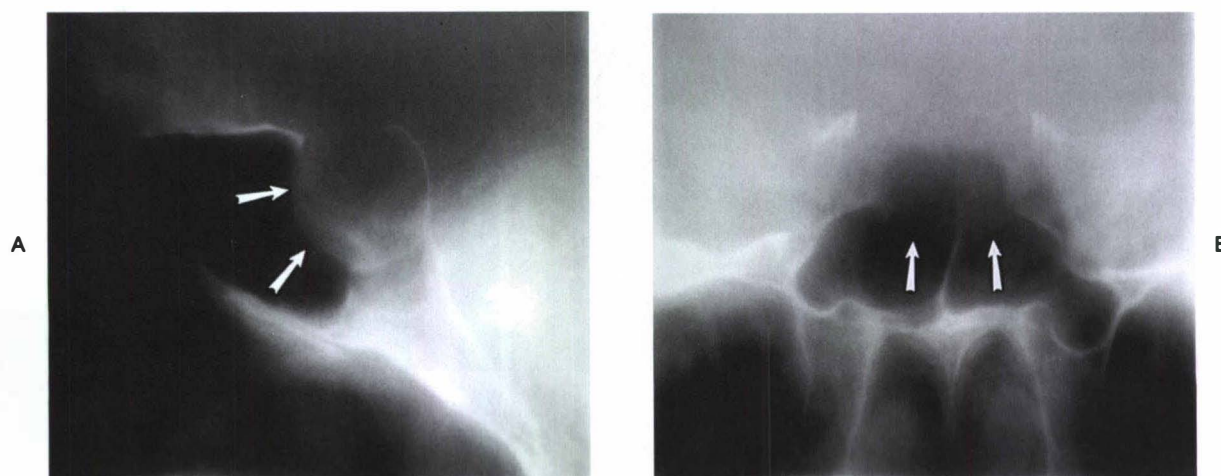
### SOFT TISSUE LESIONS AFFECTING BONY STRUCTURES

Tomography is also used to demonstrate and evaluate soft tissue neoplasms in the presence of bony structures. Because of the high density of bone and the relatively low density of soft tissue neoplasms, the actual lesion usually cannot be demonstrated, but the bony destruction caused by the tumor may be demonstrated with great clarity.

For example, neoplasms involving the pituitary gland (e.g., pituitary adenoma) usually cause bony changes or destruction of the floor of the sella turcica, which indicates the presence of a pituitary adenoma. In addition to showing destruction caused by the tumor, tomography can demonstrate bony septations in the sphenoidal sinus, which aids the surgeon in removal of the tumor (Fig. 32-4).



**Fig. 32-3** Normal branchotomogram through midplane of hilum. **A**, Linear tomogram. **B**, Trispiral tomogram demonstrating the hilar structures more clearly: 1, trachea; 2, carina; 3, left main bronchus; 4, right main bronchus; 5, intermediate bronchus; 6, right upper lobe bronchus; 7, right lower lobe bronchus; 8, left lower lobe bronchus; 9, left upper lobe bronchus.



**Fig. 32-4** Tomograms through midplane of sella turcica demonstrating destruction of floor (arrows) caused by a pituitary adenoma. **A**, Lateral tomogram. **B**, AP tomogram.

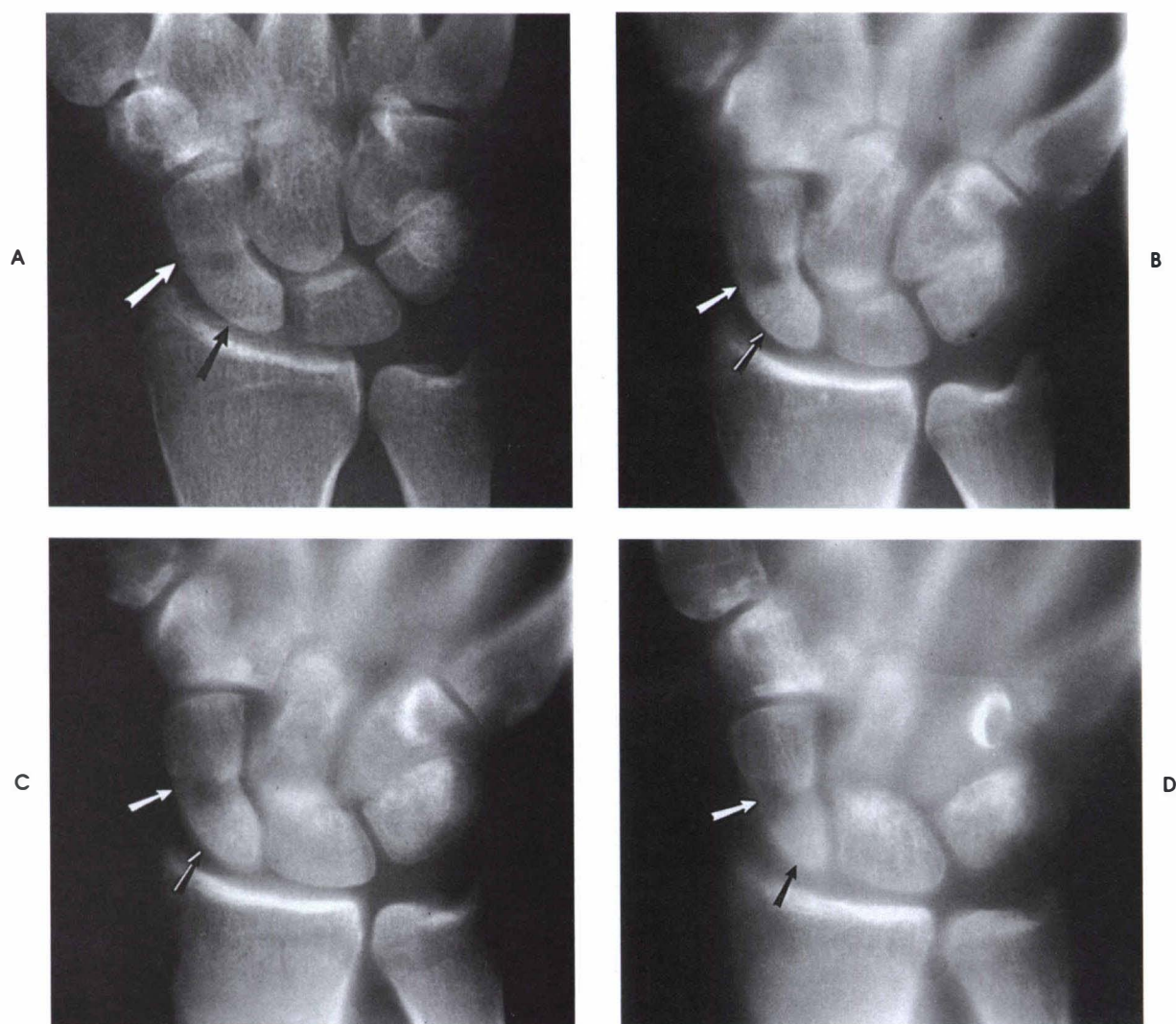


## LESIONS IN BONE

Subtle changes that may occur as a result of a pathologic process in bone tissue may be noted on conventional radiographs, but in many instances only tomography can determine the true nature and extent of the involvement (Fig. 32-5). Pathologic processes involving bony structures are normally characterized by bone destruction and changes in bone tissue or surface margins. More specifically, in tomography an attempt is made to identify the extent of bone destruction; the status of the cortex of the bone (i.e., whether destruction extends through the cortical bone); the presence of any periosteal reaction to the lesion, changes in the bone matrix, new bone formation; and the status of the zone between diseased and normal bone.

Destruction or other alterations of bone may result from a multitude of benign or malignant processes that manifest themselves in different ways. Some benign processes such as osteomyelitis are characterized by areas of bone destruction, whereas others such as osteomas appear as abnormal growths of bone from bone tissue. Some processes may exhibit a combination of bone destruction and new growth, as occurs in Paget's disease and rheumatoid arthritis.

Malignant neoplasms in bone tissue may occur in the form of primary lesions or secondary lesions resulting from the metastatic spread of cancer from another area of the body. Some forms of cancer occurring in bone exhibit areas of both destruction and new growth, whereas others exhibit only areas of extensive destruction.



**Fig. 32-5** **A**, PA wrist radiograph demonstrating healing fracture (*white arrow*) of scaphoid bone and increased density (*black arrow*) of proximal end. **B** through **D**, Tomograms at 3-mm intervals demonstrating fracture site (*white arrows*) with dense area (*black arrows*) of sclerotic bone at proximal end of scaphoid bone, consistent with aseptic necrosis.

## FRACTURES

The three major clinical applications for tomography when dealing with known and suspected fractures are (1) identification and evaluation of occult fractures, (2) better evaluation of known fractures, and (3) evaluation of the healing process of fractures.

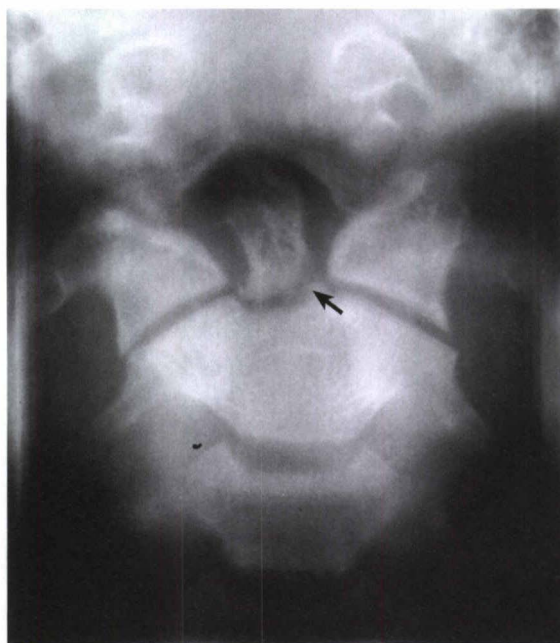
### Occult fractures

If a fracture is suspected clinically but cannot be ruled out or identified by conventional imaging techniques, tomography may be indicated. Tomography is often used when fractures are suspected in areas of complex bone structures such as the cervical spine. The cervical spine projects a myriad of confusing shadows, often hiding fracture lines and making an accurate diagnosis impossible. Tomography can identify and evaluate these occult fractures (Fig. 32-6). Knowledge of these fractures can be crucial to the plan of treatment and the prognosis for the patient.

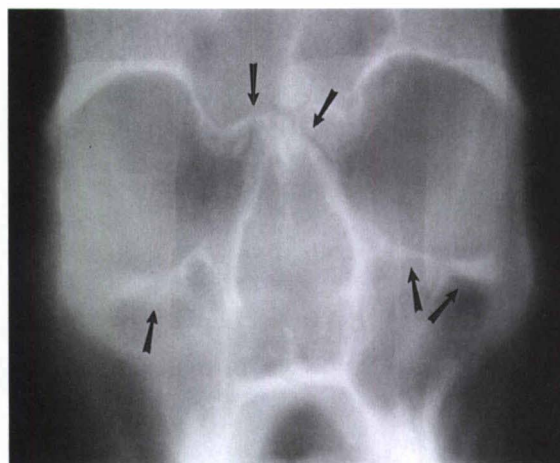
The skull is another area that frequently requires tomographic evaluation for occult fractures. The skull has many complicated bone structures that often make identification and evaluation of fractures extremely difficult without the use of tomography. The facial nerve canal that courses through the temporal bone is just one of many areas that are difficult to evaluate for fractures without tomography. Blowout fractures of the orbital floor also frequently require tomographic evaluation because of the difficulty in identifying and evaluating fractures and fragments of the thin bones composing the floor and medial wall of the orbit (Fig. 32-7).

### Known fractures

Tomography may also be used to evaluate known fractures with greater efficiency than is possible with conventional radiography. In some instances a fracture may be visualized on a conventional radiograph, but because of the complex nature of the fracture or superimposition of shadows from adjacent structures, the fracture site cannot be adequately evaluated without the use of tomography. This is often the case in hip fractures involving the acetabulum. In acetabular fractures, portions of the acetabulum are often broken into many fragments that may be difficult to identify. With tomography the fragments and any possible femoral fracture can be evaluated before an attempt is made to reduce the fracture.



**Fig. 32-6** AP tomogram of C1-C3 demonstrating complete fracture at base of dens (arrow).



**Fig. 32-7** Frontal tomogram using reverse Caldwell method, demonstrating multiple facial fractures (arrows).



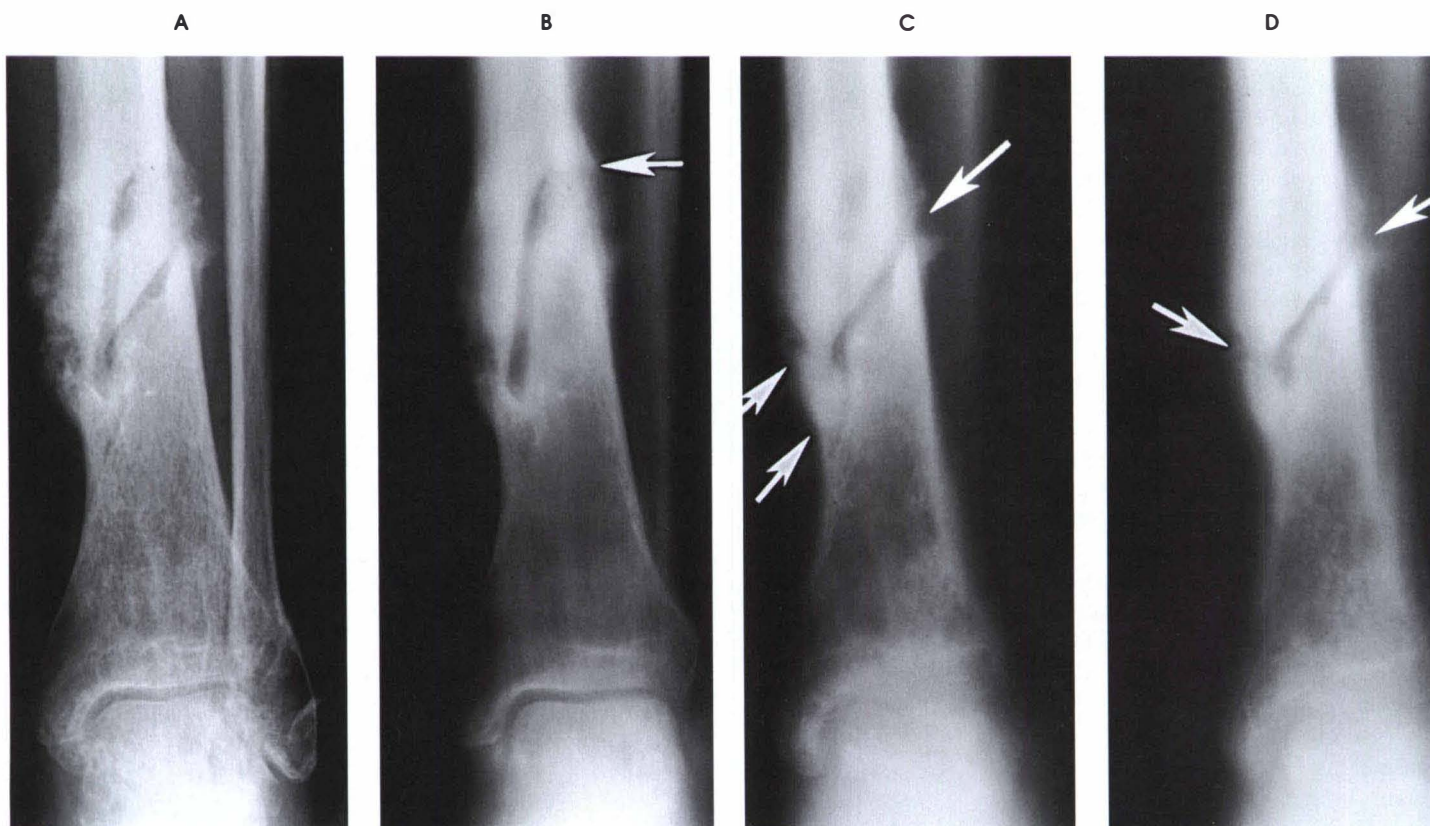
### Healing fractures

Tomography may also be used to evaluate the healing process of fractures when conventional imaging techniques prove inadequate because of overlying shadows of fixation devices, adjacent structures, or bone callus. In these situations, tomography may be essential to assess whether the bone is healing properly throughout the fracture site. Tomography also can identify areas of incomplete healing in the fracture (Fig. 32-8).

### ABDOMINAL STRUCTURES

Because of the relatively homogeneous densities of abdominal structures, both radiographic and tomographic imaging of this area are most effectively performed in conjunction with the use of contrast materials. Zonography is usually preferred for tomographic evaluation of these organs. As previously stated, zonography produces focal plane images of greater contrast than is possible with thin-section tomography. This increased level of contrast aids in visualization of the relatively low-density organs of the abdomen. The extensive blurring of remote structures that occurs with wide-angle tomography is not necessary in the abdomen because relatively few high-density structures exist in this area to compromise the zonographic imaging of the abdominal structures. Thick sections of organs are depicted with each zonogram, and entire organs can be demonstrated in a small number of tomographic sections.

A circular motion with an exposure angle of 8 or 10 degrees is recommended for use in the abdomen. Occasionally, an angle of 15 degrees may be necessary to eliminate bowel-gas shadows if the smaller angle does not provide adequate effacement (blurring) of the bowel.



**Fig. 32-8** **A**, AP distal tibia radiograph demonstrating questionable complete union of fractures. **B**, AP tomogram of same patient as in **A**, demonstrating incomplete union of longitudinal fracture (arrow). **C** and **D**, Tomograms demonstrating incomplete union of oblique fractures (arrows) through shaft of tibia of same patient as in **A** and **B**. **C**, Tomogram obtained 0.5 cm to **B**. **D**, Tomogram obtained  $\frac{3}{8}$  inch (1 cm) posterior to **B**.



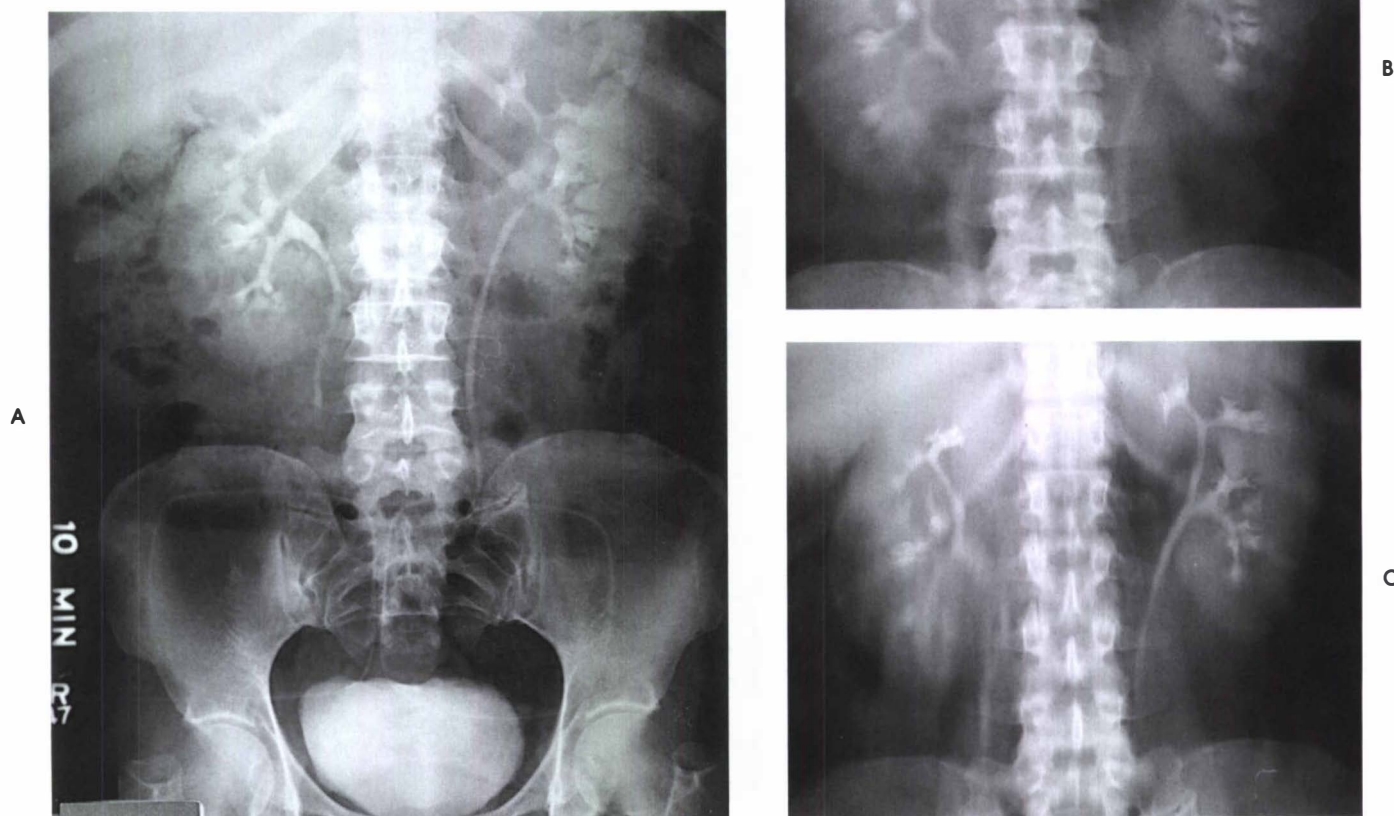
Zonography using a linear movement is not recommended because it does not provide adequate blurring of structures outside the focal plane. If a linear movement is employed, an exposure angle of 15 degrees should be used to provide adequate blurring. Linear tomography does not produce accurate focal plane images because of the incomplete blurring effect of structures oriented parallel to the tube movement. Although the possibility of false image formation exists with circular tomography, the image of the focal plane is far more accurate than with linear tomography. Linear tomograms are higher in contrast than circular tomograms, but this is actually a result of the linear streaking caused by the incomplete blurring characteristics of linear motion. Circular motion, on the other hand, produces an accurate focal plane image with slightly less but even contrast.

The most common tomographic examinations of the abdomen are of the kidneys and biliary tract. These examinations are normally performed with contrast material.

### Renal tomography

Many institutions include tomography of the kidneys as part of the intravenous urography (IVU) procedure (Fig. 32-9). The tomograms are usually taken immediately after bolus injection of the contrast material. At this time the kidney is entering the nephrogram phase of the IVU, in which the nephrons of the kidney begin to absorb the contrast material, causing the parenchyma of the kidney to become somewhat radiopaque. Zonography may then be used to demonstrate lesions in the kidney that may have been overlooked with conventional radiography.

Another typical renal tomographic examination is the nephrotomogram. The major difference between this and the IVU is the method of introduction of the contrast material. In nephrotomography the contrast material is drip-infused throughout the examination instead of introduced in a single bolus injection. This method allows for a considerably longer nephrographic effect because the nephrons opacify the kidney as they continuously absorb and excrete the contrast material.



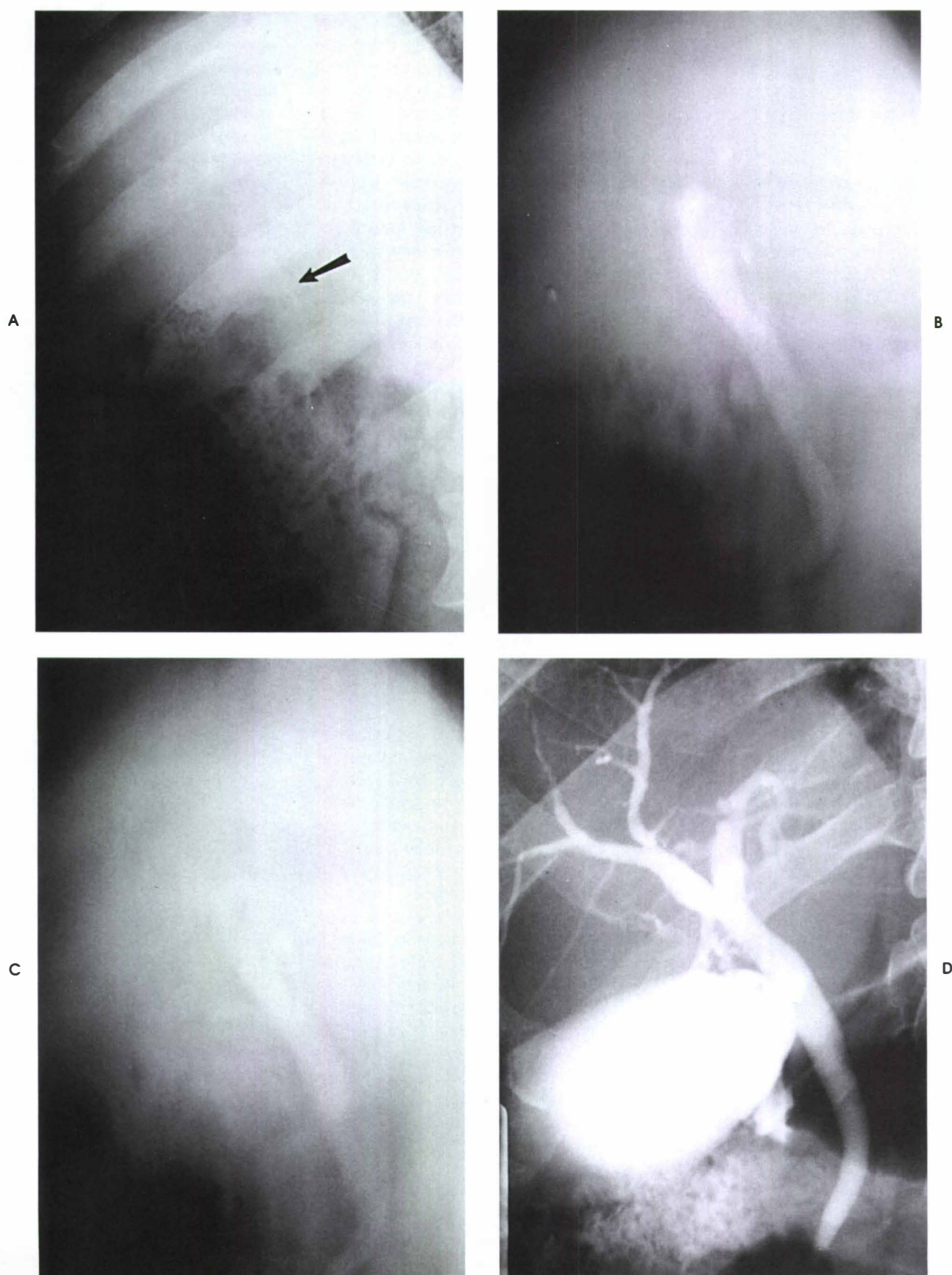
**Fig. 32-9** **A**, IVU, AP abdomen radiograph. Bowel shadows obscure kidneys. **B**, AP tomogram of same patient as in **A**, obtained through midplane of kidneys using 8-degree circular motion. Bowel shadows are absent, and compared with **C**, visualization of kidneys is improved. **C**, AP tomogram of same patients as in **A** and **B** and at same levels as in **B**, but employing 20-degree linear motion. Note linear streaking and loss of detail of collecting systems and kidney borders.

**Intravenous cholangiograms**

The biliary tract is another organ system that may require tomography for adequate evaluation. If an oral cholecystogram does not yield sufficient information for a diagnosis or if biliary ductal disease is suspected in a patient after cholecystectomy, an intravenous cholangiogram (IVC) may be indicated. The IVC is performed by infusing a solution of the contrast material Cholografin into the bloodstream, where it is first absorbed into and then excreted by the liver into the biliary ducts. The drip infusion should be administered slowly over approximately 20 to 30 minutes to reduce the possibility of anaphylactic shock.

Opacification of the ducts is generally not great enough for adequate evaluation with conventional radiography alone. The ducts may also be partially or completely obscured by the superimposition of structures in the abdomen. Even if the ducts may be well opacified on conventional radiographs, tomography should be performed to obtain information not provided by conventional radiography (Fig. 32-10).

Zonography is normally used for IVCs. Sometimes, however, more blurring or a thinner tomographic section is desired. For those instances a trispiral or hypocycloidal motion may be preferred. If a linear motion is to be employed, an exposure angle of 15 to 20 degrees should be used.



**Fig. 32-10** **A**, IVC, AP oblique projection, RPO body position. Faintly opacified common bile duct (*arrow*) is obscured by bowel gas and liver. **B** and **C**, RPO tomograms of same patients as in **A** through level of common bile duct. Visualization of duct is improved over the plain image study in **A**. **D**, Transhepatic cholangiogram of same patient as in **A** to **C**.



## Basic Principles of Positioning

Rarely in conventional radiography does one single radiographic image contain all the diagnostic information necessary to make an accurate diagnosis. This is also true in tomography; one series of tomograms in a single plane usually does not contain enough information to make an accurate diagnosis. As in radiography, two or more image planes are usually required for most tomographic examinations. For bilateral structures such as the internal acoustic canals, only one radiograph may be used. In such cases, tomograms of the contralateral side are obtained for comparison.

Many fundamental radiographic body positions are used in tomography. The AP and lateral projections are basic to most tomographic examinations. Occasionally a special oblique projection may be necessary for optimal visualization of the part under investigation. The radiographer should observe the following positioning guidelines:

- In tomography, orient the structures either parallel or perpendicular to the tomographic plane. For example, when evaluating structures in the base of the skull, position the patient's head for a basal projection so that the base of the skull is oriented parallel to the section plane. This parallel position not only produces images that are more anatomically correct but also reduces the total number of tomograms necessary to cover the area of interest. If the base of the skull is not parallel but is slightly oblique, more tomograms are required to evaluate the area of interest adequately. This also pertains to other areas of the body in which large, relatively flat surfaces occur, such as in long bones.
  - When producing tomograms of long bones such as the femur, adjust the long axis of the bone to be parallel to the tomographic plane.
  - For some structures such as the sella turcica, use a perpendicular orientation for tomography. Because the presence of a pituitary adenoma usually affects the floor of the sella, orient the floor perpendicular to the section plane. AP and lateral radiographs are routinely used; for both images, the floor remains perpendicular to the tomographic plane.
- Very few areas in radiology place greater demand on the knowledge and ability of the radiographer than the field of tomography. The tomographer must possess a strong background and understanding of anatomy and the spatial relationships of the structures of the body (see Chapter 27). The tomographic radiographer must know where certain structures of the general body parts are located, the best way to position those structures for tomographic examination, the depth at which particular structures are located, and the way the tomographic image should look. On many occasions, even experienced tomographers must rely heavily on the knowledge and instruction of the radiologist monitoring the examination. The radiographer and radiologist should work together closely because no two tomographic examinations are exactly alike and each patient must be considered individually. The radiographer should observe the following guidelines when assisting with the tomographic examination:
- Provide the radiologist with an adequate clinical history of the patient. If this information is not provided on the examination requisition, obtain it by studying the patient's medical records or interviewing the patient.
  - Review and discuss this clinical information and any pertinent radiographs with the radiologist before beginning the examination. After reviewing the information, the radiologist and radiographer can then decide on the area of interest, the optimum position, the size of the field of exposure, the type of blurring motion and exposure angle to be used, the separation intervals between tomographic sections, and the parameters for the fulcrum height. The most complex motion available should be used whenever possible.
  - Complete all equipment preparation before positioning the patient. This reduces the amount of time that the patient is required to maintain an often uncomfortable position.
  - Briefly and simply explain the procedure to the patient, and offer a rough estimate of the expected length of the examination. Many patients are under the mistaken impression that the procedure consists of a few radiographs taken in a matter of minutes and that they will then be permitted to leave. They are not aware that they will be required to maintain a certain position throughout the procedure. The patient who knows what to expect will be better able to cooperate throughout the lengthy examination.
  - Ensure the patient's comfort, which is extremely important. The use of a suitable table pad is recommended for tomographic examinations. A table pad that is 1½ inches (3.8 cm) thick adds an insignificant amount to the overall patient thickness and greatly increases the patient's comfort. If uncomfortable, even the most cooperative patient will be unable to hold still for the examination.
  - When needed, use angle sponges and foam blocks to help the patient maintain the correct position. Do not, however, use foam sponges in tomographic examinations of the head. Section intervals of 1 or 2 mm are often employed in this area, and foam sponges do not give firm enough support to the head. With little change in pressure the head may move, drastically altering the desired focal plane levels. Use folded towels to support the head if needed; they offer greater resistance to any downward pressure.

## Immobilization Techniques

The most effective immobilization technique is the radiographer's instructions to the patient. No amount of physical restraint can keep patients from moving if they do not fully understand the importance of holding still from the first preliminary image to the end of the tomographic series. The radiographer should observe the following guidelines:

- Because suspension of respiration is mandatory in examinations of the chest and abdomen, give explicit breathing instructions to the patient for examinations of these areas.
- In chest tomography, instruct the patient to take a consistent, uniform deep breath for each tomogram. Caution the patient not to strain to take in the maximum breath because the patient may have difficulty in holding the breath during the exposure. Tell the patient to take a moderately deep breath that can be comfortably held for the duration of the tomographic exposure. This not only allows for optimum inflation of the lungs but also provides consistency between the focal plane levels throughout the tomographic series. Consistency in inspirations is vitally important if the area of interest is located near the diaphragm. Slight variations in the amount of air taken in may result in obscuring of the area of interest by the elevated diaphragm. Suspension of respiration is also necessary to prevent blurring of structures by the breathing motion.
- Have the patient suspend respiration in the expiratory phase in examinations of the abdomen to elevate the diaphragm and visualize more of the abdomen. As in chest tomography, the suspension of respiration assists in maintaining consistency in tissue planes and reduces motion artifacts.

- Use suspended respiration techniques in tomographic examinations of the head if needed. Unwanted motion of the head may occur when obese patients or patients with large breasts are positioned in the right anterior oblique (RAO) body position for lateral skull tomography. This problem may be resolved by having the patient suspend respiration during the exposure or by turning the patient over into a left posterior oblique (LPO) body position.
- Mark the entrance point of the central ray on the patient's skin. If the patient moves, this mark can be used as a reference point for repositioning, eliminating the need to take another scout image to recheck the position. If the mark is made with a grease pencil, it can easily be removed after the examination.
- When performing tomographic examination of the skull in the lateral position, place a small midline mark on the patient's nasion to facilitate measuring for the midline tomogram and to recheck the position between the scout image and the actual tomographic series. By ensuring that this mark is still at the same level from the tabletop, the interpupillary line is still perpendicular to the tabletop, and the central ray is still entering at the reference mark, the correct position can be maintained throughout the examination.

## Scout Tomograms

Three preliminary tomograms are usually taken to locate the correct levels for the tomographic series. One tomogram is taken at the level presumed to be at the middle of the structure or area to be examined. The other two scout tomograms are taken at levels higher and lower than this midline tomogram. The separation interval between these tomograms depends on the thickness of the structure. Tomograms of small structures such as those found in the skull may be made at 5-mm or 1-cm intervals for the preliminary images. After the correct planes have been determined, the tomographic series is taken at smaller intervals. When the total depth of the area of interest is several centimeters thick, the separation interval for these scout tomograms is increased to  $\frac{3}{4}$  inch (1.9 cm) or more. Table 32-1 includes separation intervals for the preliminary tomograms and tomographic series. The following guidelines are observed:

Use external landmarks as reference points to assist in determining the proper fulcrum level.

- In some cases, such as chest lesions that can be identified on PA and lateral chest radiographs, take measurements from these radiographs to aid in the selection of the scout tomogram levels. For example, to determine the proper level for AP tomography of a chest lesion, measure the distance on the conventional lateral chest radiograph from the posterior chest wall to the middle of the lesion. Add this distance to the thickness of the table pad. Ensure that a scout tomogram taken at this fulcrum height is in the middle of the lesion.
- Use a similar process for tomography in the lateral position, taking the measurements from the AP chest radiograph.
- If the area of interest is not localized on the scout images, take a plain radiograph using the same centering as for the preliminary tomograms. This confirms that the area of interest is actually in the collimated field of interest and recentering is not required.



**TABLE 32-1**

Positioning for tomography

Examination part	Projection	Central ray position	Preliminary tomographic levels	Separation intervals	Comments
Sella turcica	AP	Glabella	1.5, 2.5, and 3.5 cm anterior to tragus	2 mm	Shield eyes
	Lateral	2.5 cm anterior and superior to tragus	21, 0, and 1 cm to midline of skull	2 mm	Place water bag under patient's chin for support
Middle ear (internal acoustic canal, facial nerve canal)	AP	Midpoint between inner and outer canthi	-0.5, 0, and 0.5 mm to tip of tragus	1 or 2 mm	Shield eyes
	Lateral	5 mm posterior and superior to external acoustic canal	At level of outer canthus and 1 and 2 cm medial	1 or 2 mm	Place water bag under patient's chin for support
Paranasal sinuses (general survey) and orbital floors	Reverse Caldwell	Intersection of midsagittal plane and infraorbital rims	22, 0, and 2 cm to level of outer canthus	3 to 5 mm	Infraorbitomeatal line should be perpendicular to tabletop
	Lateral	2 cm posterior to outer canthus	23 and 3 cm to midline of skull	3 to 5 mm	Place water bag under patient's chin for support
Base of skull	Submento-vertex	Midpoint between angles of mandible	21, 0, and 1 cm	2 or 3 mm	Orbitomeatal line should be parallel to tabletop
Cervical spine	AP	To vertebral body/bodies of interest	0, 22, and 24 cm to external acoustic meatus	3 or 5 mm	
	Lateral	To vertebral body/bodies of interest	22, 0, and 2 cm from midline of back	3 or 5 mm	Place water bag under patient's chin for support and two or more on neck to equalize density for entire cervical spine
Thoracic spine	AP	To vertebral body/bodies of interest	3, 5, and 7 cm from tabletop	5 mm	Flex knees slightly to straighten spine
	Lateral	To vertebral body(ies) of interest	22 and 2 cm from midline of back	5 mm	Flex knees, and place sponge against patient's back for support



**TABLE 32-1**

Positioning for tomography—cont'd

Examination part	Projection	Central ray position	Preliminary tomographic levels	Separation intervals	Comments
Lumbar spine	AP	To vertebral body/bodies of interest	4, 7, and 10 cm from tabletop	5 mm	Flex knees slightly to straighten spine
	Lateral	To vertebral body/bodies of interest	22, 0, and 2 cm from midline of back	5 mm	Flex knees and place sponge against patient's back for support
Hip	AP	Head of femur	22, 0, and 2 cm for greater trochanter	5 mm	Place water bag over area of greater trochanter to equalize density to hip
	Lateral (frog leg)	Head femur	5, 7, and 9 cm from tabletop	5 mm	Place water bag over area of femoral neck to equalize density
Limbs	AP and lateral	At area of interest	5 mm to 1.5 cm, depending on size of limb	2 to 5 mm	Adjust limb to be parallel to tabletop
Chest (whole lung and hila)	AP	9 to 12 cm below sternal notch	10, 11, and 12 cm above tabletop	1 cm	Use through filter (80 to 90 kVp)
	Lateral	Midchest at level of pulmonary hila	25, 0, and 15 cm from midline of back	1 cm	Place sponge against patient's back for support
Chest (localized lesion)	AP and lateral	Measure distance to lesion from chest wall on plain radiographs, and center at this point on patient	Measure distance to lesion on lateral chest image and thickness of table pad; 22, 0, and 12 cm from measurement	2, 3, or 5 cm	Use low kVp (50 to 65) for high contrast
Nephrotomogram	AP	Midpoint between xiphoid process and top of iliac crests	7 cm for small patient; 9 cm for average patient; 11 cm for large patient	1 cm	Use 8 to 10 degrees of circular movement or 15 to 20 degrees of linear movement
Intravenous cholangiogram	AP oblique, 20 degree right posterior oblique (RPO)	10 cm lateral to lumbar spine	10, 12, and 14 cm for small patient; 12, 14, and 16 cm for average patient; 13, 16, and 19 cm for large patient	5 mm to 1 cm	Use 8 to 10 degrees of circular movement or 15 to 20 degrees of linear movement

## General Rules for Tomography

The following rules are essential:

- Know the anatomy involved.
- Position the patient as precisely as possible.
- Use proper immobilization techniques.
- Use a small focal spot for tomography of the head and neck and limbs.
- Use a large focal spot for other areas of the body where fine recorded detail is not crucial.
- Use low kVp when high contrast is desired.
- Use high kVp when contrast differences between structures must be reduced; for example, whole-lung tomography requires a high kVp—80 to 90 kVp—in conjunction with a trough filter.
- When necessary, use water or flour bags to absorb primary or secondary radiation. For example, in lateral cervical spine tomography, place the bags on the upper cervical spine area to reduce the density difference between the spine and dense shoulders. Collimate the beam as tightly as possible to reduce patient exposure and improve contrast.
- Shield the patient, especially the eyes, in examinations of the skull and upper cervical spine.
- Use the proper blurring motion. In general, use the most complex blurring motion available. If zonography is required, use a circular motion. If only linear motion is available, take care to orient the part correctly to the direction of the tube.
- Mark each tomogram with the correct layer height. This may be done by directly exposing lead numbers on each tomogram or by marking each tomogram after it is processed. Another technique is to shift vertically the right or left marker used on each successive image. If the level of the first image is known, the correct level for each successive image can be determined. If multiple tomograms are taken on one image receptor, follow the same shift sequence to avoid confusion in marking the layer heights.

## TOMOGRAPHY OF THE SKULL

Strict immobilization techniques must be used for any tomographic examination of the skull. Reference points should be marked on the patient for rechecking of the position.

The basic skull positions are outlined in the following sections and are to be used in conjunction with Table 32-1.

### AP projection

- Adjust the patient's head to align the orbitomeatal line (OML) and the midsagittal plane perpendicular to the tabletop.
- Ensure that the distances from the tabletop to each tragus (the tongue-like projection of the ear just in front of the external acoustic meatus) are equal; this indicates that the head is positioned perfectly.

### AP projection: reverse Caldwell method

- Position the infraorbitomeatal line (IOML) and the midsagittal plane perpendicular to the tabletop.
- Ensure that the tragi are equidistant from the tabletop.

### Lateral projection

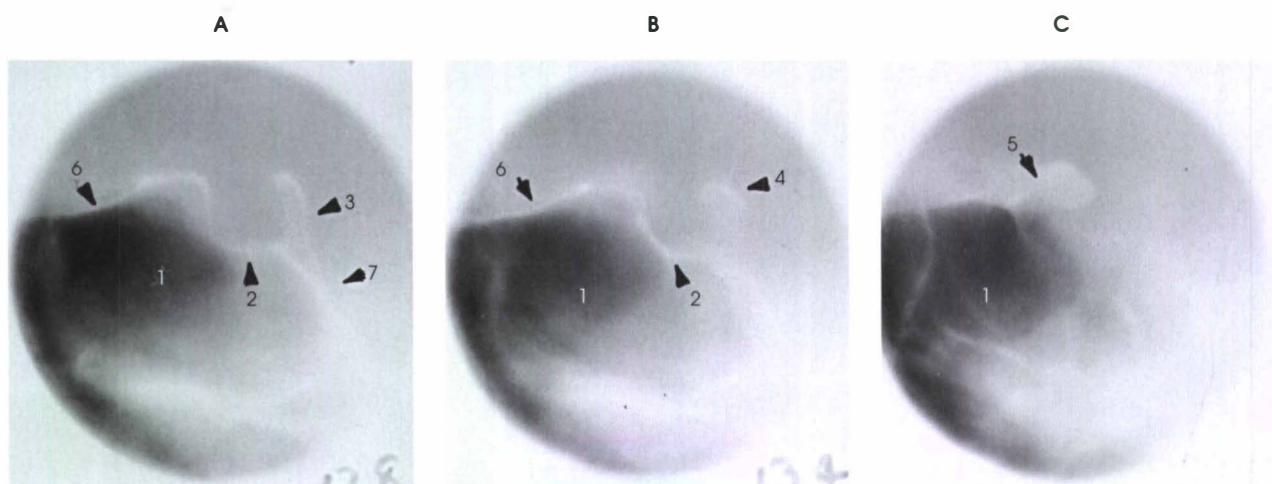
- Position the midsagittal plane parallel to the tabletop.
- Ensure that the interpupillary line is perpendicular to the tabletop.
- Check that the OML is approximately parallel to the lower border of the image receptor.

## TOMOGRAPHY OF OTHER BODY PARTS

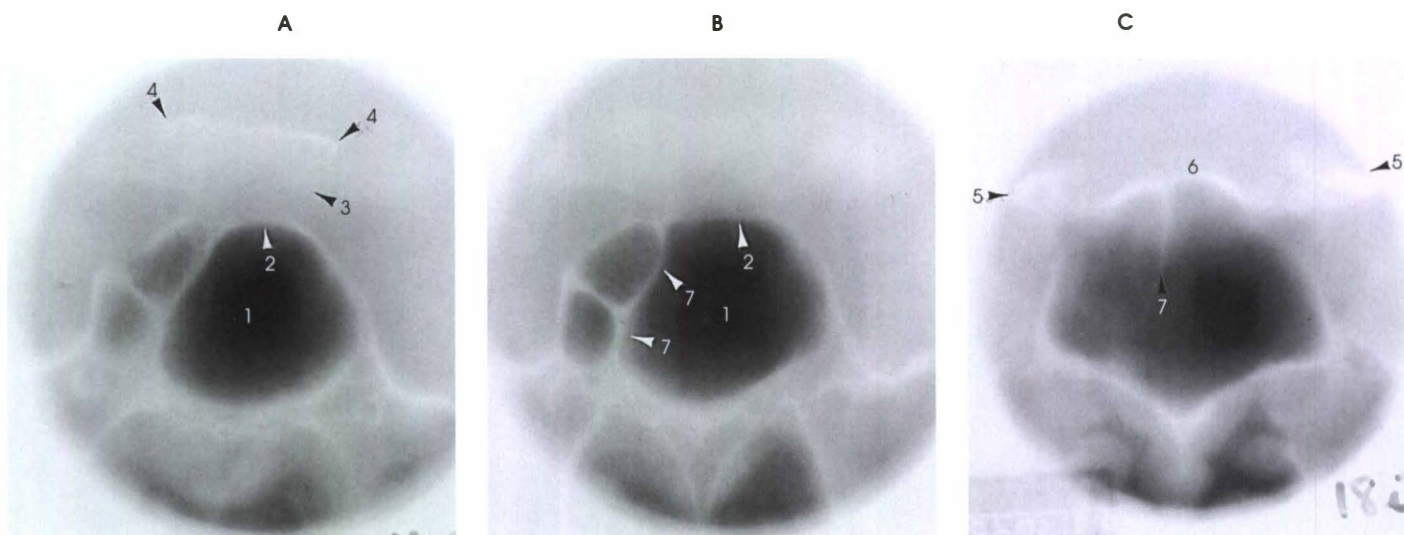
Standard radiographic projections (AP, lateral, and oblique) are used for most areas of the body. The same general rules of tomography apply to all areas. In general the projection that best demonstrates the area of interest in a conventional radiograph is usually the best for tomography. Selected tomograms are shown in Figs. 32-11 to 32-16.

Information on panoramic tomography, which is used to demonstrate the entire mandible and temporomandibular joint using one tomographic type of exposure, is provided in Chapter 21 of this atlas.



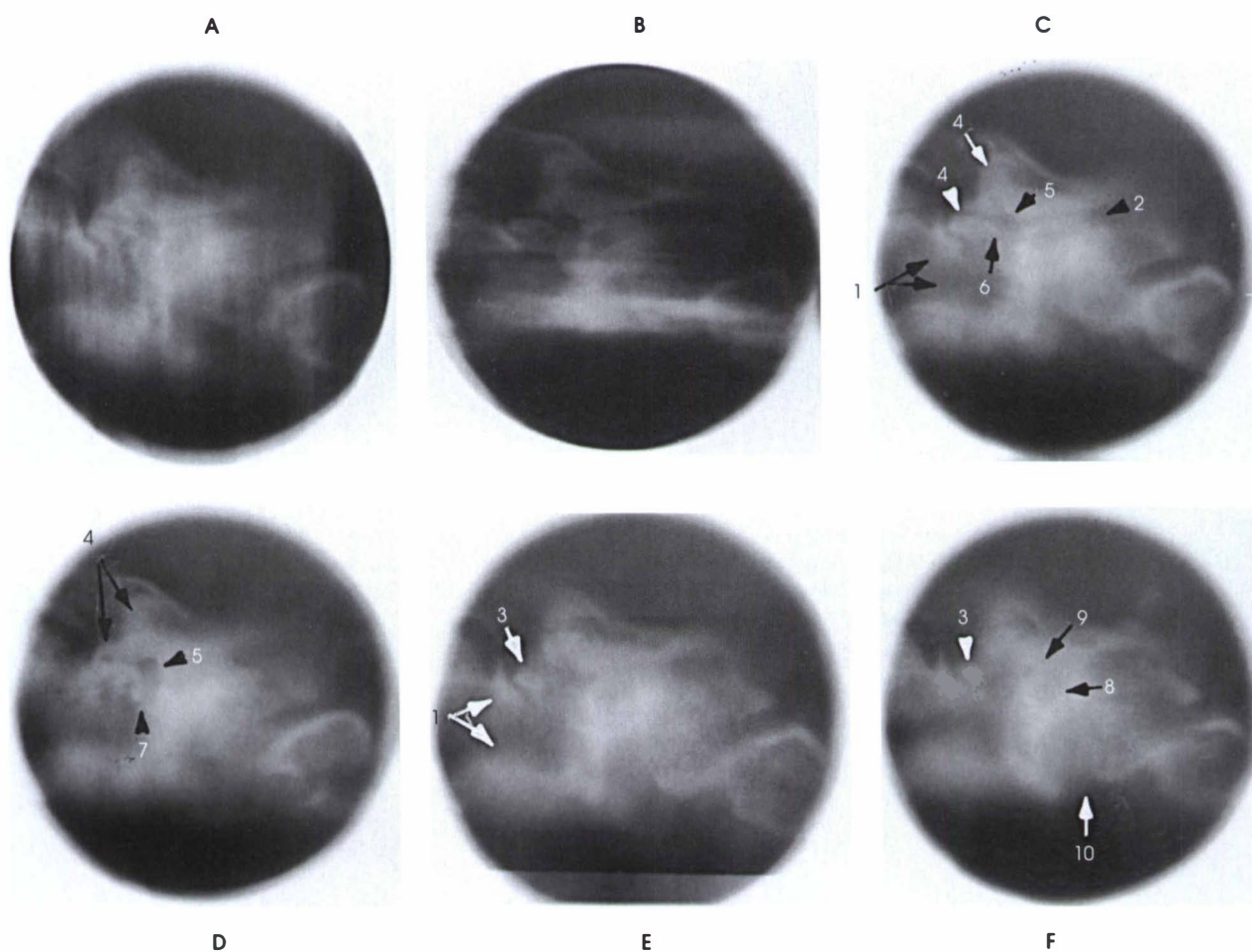


**Fig. 32-11** Lateral sella turcica. **A**, Tomogram through midplane of sella. **B**, Tomogram 5 mm lateral to **A**. **C**, Tomogram  $\frac{3}{8}$  inch (1 cm) lateral to **A**. 1, Sphenoidal sinus; 2, floor of sella; 3, dorsum sellae; 4, posterior clinoid process; 5, anterior clinoid process; 6, planum sphenoidale; 7, clivus.

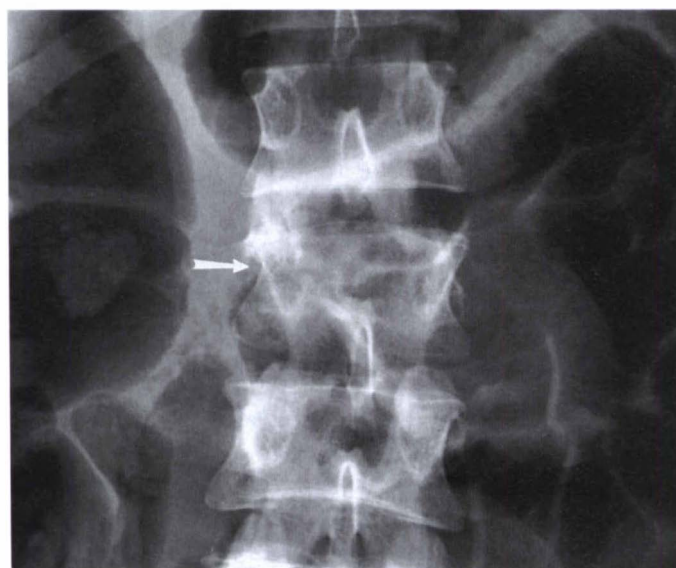


**Fig. 32-12** AP tomograms of sella turcica. **A**, Tomogram in posterior plane of sella turcica. **B**, Tomogram  $\frac{3}{8}$  inch (1 cm) anterior to **A**, demonstrating floor of sella. **C**, Tomogram 2 cm anterior to **A**, demonstrating anterior clinoid processes. 1, Sphenoidal sinus; 2, floor of sella; 3, dorsum sellae; 4, posterior clinoid processes; 5, anterior clinoid processes; 6, planum sphenoidale; 7, septations of sphenoidal sinus.

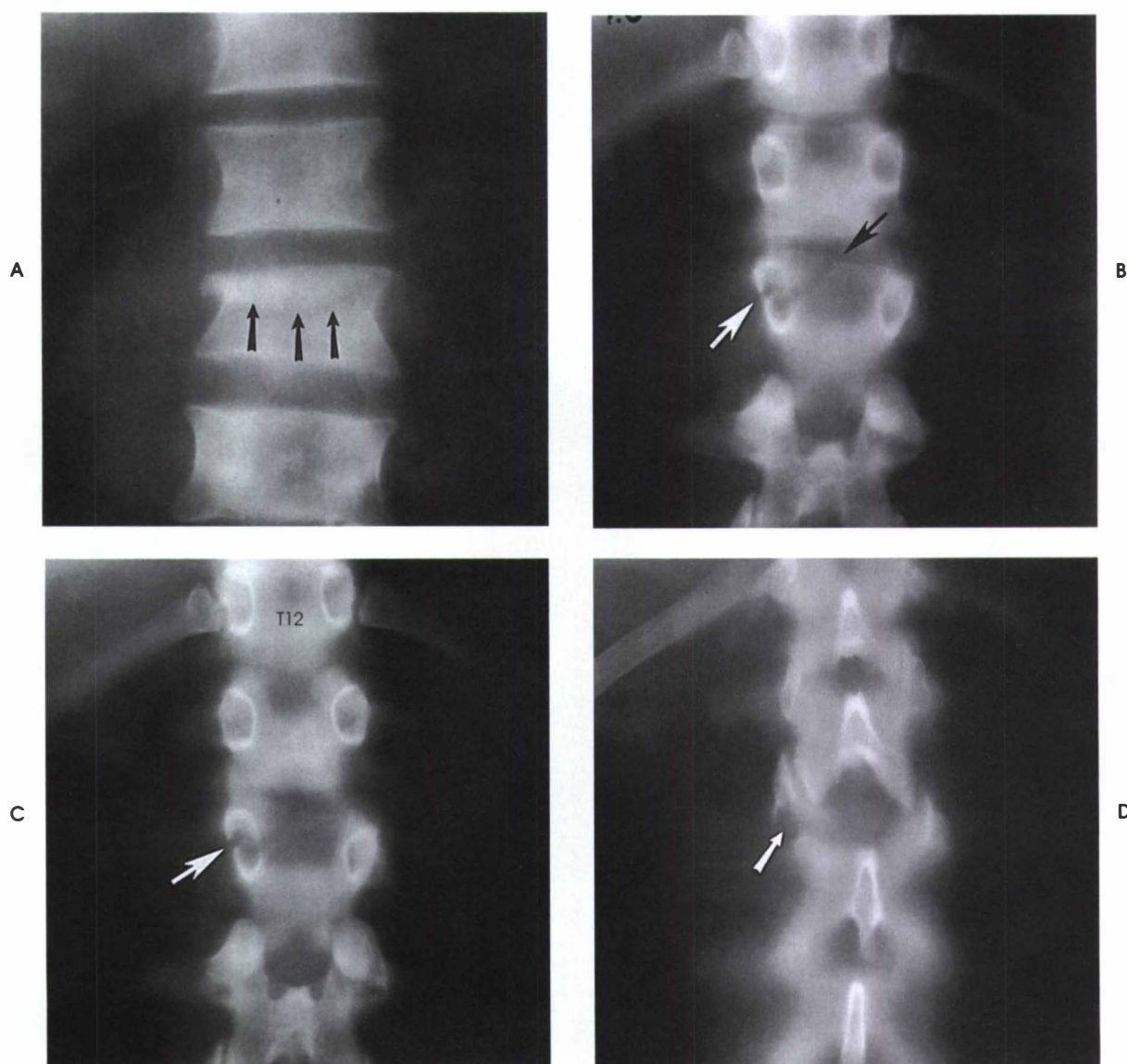




**Fig. 32-13** AP tomograms of middle ear. Longitudinal linear (A), transverse linear (B), and trispiral (C) motion are at same posterior level of middle ear. Note improved visualization of structures with trispiral motion. AP tomograms anterior to level of C by 2 mm (D), 4 mm (E), and 6 mm (F). 1, External acoustic canal; 2, internal acoustic canal; 3, ossicular mass, including malleus, incus, and lateral and superior semicircular canals; 4, acoustic ossicles; 5, vestibule; 6, fenestra vestibuli; 7, fenestra cochlea; 8, cochlea; 9, cochlea portion of facial nerve canal; 10, carotid canal.



**Fig. 32-14** AP lumbar spine showing suspected fracture (arrow) of L2 (see Fig. 32-28).



**Fig. 32-15** AP tomograms further delineating fracture site shown in AP radiograph in Fig. 32-27. **A**, Tomogram through anterior plane of vertebral body, demonstrating wedging of vertebral body of L2 (arrows). **B**, AP tomogram 2 cm posterior to A through lane of pedicles. Fracture line extends through right pedicle (white arrow) and vertebral body (black arrow). **C**, AP tomogram 3 cm posterior to A, demonstrating displacement of fracture (arrow). **D**, AP tomogram 4 cm posterior to A, demonstrating displaced fracture (arrow) of superior articular process of L3.



**Fig. 32-16** AP tomograms of hip with fixation device at same level, comparing different blurring motions: **A**, Trispiral; **B**, circular; **C**, longitudinal linear; **D**, oblique linear.

## Conclusion

Tomography has changed dramatically since the early days of Bocage and des Plantes. Their crude devices bear little resemblance to today's modern tomographic machines. Tomography has been widely accepted as an extremely useful diagnostic tool. Linear tomographic machines can now usually be found in even the smallest hospitals. Many large hospitals have one or more linear units in addition to a pluridirectional machine.

Computed tomography (CT) and magnetic resonance imaging (MRI) have certainly proved themselves as extremely valuable diagnostic tools, and in most cases their images are far superior to those of conventional tomography. However, in many instances tomography can provide sufficient information for an accurate diagnosis at a cost far less than that of the more sophisticated imaging modalities. Furthermore, most MRI and CT scanners are extremely busy, and many cannot handle the high workload. Conventional tomography can often answer diagnostic questions satisfactorily or at least screen patients for further evaluation by the other, more sophisticated imaging modalities.



Although many equipment manufacturers still market a variety of x-ray machines capable of performing linear tomography, the more expensive, complex motion tomography units have been dropped from their product lines. In this era of cost containment, most health care facilities can ill afford to dedicate a piece of radiographic equipment solely for conventional tomography. Equipment manufacturers have taken note of this and have responded accordingly. Most equipment companies now offer a variety of tomographic options to their line of radiographic and fluoroscopic and fixed radiographic units.

"Add-on" tomography devices of the twenty-first century look nothing like their crude predecessors, with their long metal bar attachments with sliding sleeves and thumbscrews to adjust fulcrum heights. The new units are simple to connect and usually provide push-button control for adjusting amplitude and layer height. Some of these devices do not even have a mechanical linkage but rather use microprocessor-controlled motorized drive units for the tube and Bucky, or other image receptor, trays to impart their motion. Although the linear tomographic images produced by these units do not quite compare with those produced by pluridirectional units, they are often considered quite acceptable. In this cost-conscious era, tomography will likely remain for many years a valuable diagnostic imaging tool for both small and large hospitals.

## Definition of Terms

**adjustable fulcrum** Tomographic fulcrum that is either raised or lowered to achieve the desired fulcrum height (see planigraphic principle).

**body-section radiography** See *tomography*.

**complex tomographic motion** See *pluridirectional tomographic motion*.

**exposure angle** Degree of arc angulation described by the movement of the x-ray tube and cassette during a tomographic motion.

**fixed fulcrum** Tomographic fulcrum remains at a fixed height (see *Grossman principle*).

**focal plane** Plane of tissue that is in focus on a tomogram.

**fulcrum** Point of axis of rotation for a tomographic motion.

**Grossman principle** Tomographic principle in which the fulcrum or axis of rotation remains at a fixed height; the focal plane level is changed by raising or lowering the tabletop through this fixed point to the desired height.

**laminagraphy** See *tomography*.

**linear tomographic motion** Basic tomographic movement that occurs when x-ray tube and cassette movement occurs with the longitudinal axis of the tomographic table.

**moving film roentgenogram** See *tomography*.

**phantom images** False tomographic images that appear but do not represent an actual object or structure within the focal plane; these images are created by the incomplete blurring or the fusion of the blurred margins of some structures characteristic to the type of tomographic motion used.

**planigraphic principle** Tomographic principle in which the fulcrum, or axis of rotation, is raised or lowered to alter the level of the focal plane; the tabletop height remains constant.

**planigraphy** Synonymous with *tomography*.

**pluridirectional tomographic motion** Tomographic motion in many different directions.

**section thickness** Tomographic plane that is in maximum focus.

**stratigraphy** Synonym for *tomography*.

**tomographic angle** See *exposure angle*.

**tomography** Radiographic technique that depicts a single plane of tissue by blurring images of structures above and below the plane of interest.

**unidirectional tomographic motion** Tomographic motion in only a linear direction.

**zonography** Tomography that uses exposure angles of 10 degrees or less to depict thick sections or zones of tissue.

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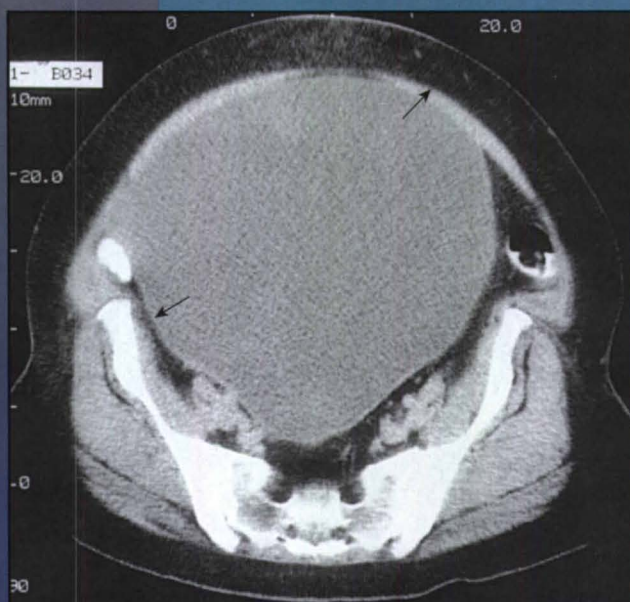


33

# COMPUTED TOMOGRAPHY

LORRIE L. KELLEY

Abdominal CT image demonstrating extremely large ovarian cyst (arrows).



## OUTLINE

Fundamentals of computed tomography, 330  
Computed tomography and conventional radiography, 330  
Historical development, 333  
Technical aspects, 335  
System components, 336  
Diagnostic applications, 340  
Contrast media, 342  
Factors affecting image quality, 342  
Special features, 344  
Comparison of computed tomography and magnetic resonance imaging, 351  
The future, 352  
Definition of terms, 352



## Fundamentals of Computed Tomography

*Computed tomography (CT)\** is the process of creating a cross-sectional tomographic plane of any part of the body (Fig. 33-1). For CT a patient is scanned by an x-ray tube rotating about the body part being examined. A detector assembly measures the radiation exiting the patient and feeds back the information, referred to as primary data, to the host computer. Once the computer has compiled and calculated the data according to a preselected *algorithm*, it assembles the data in a *matrix* to form an *axial* image. Each image, or *slice*, is then displayed on a *cathode ray tube (CRT)* in a cross-sectional format.

\*Almost all italicized words on the succeeding pages are defined at the end of this chapter.

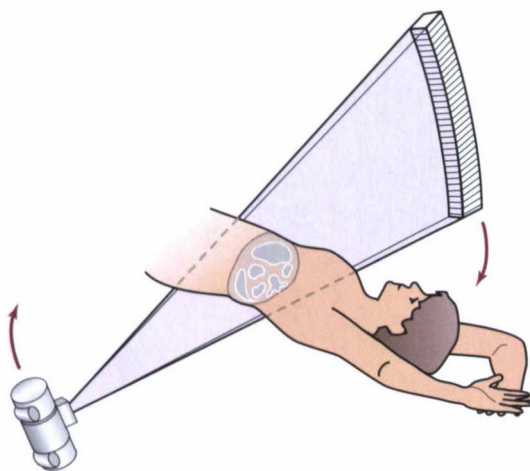
In the early 1970s CT scanning was only used clinically for imaging of the brain. Furthermore, the first CT scanners were capable of producing only axial images and thus were called *CAT (computed axial tomography)* units by the public; this term is no longer accurate because images can now be created in multiple planes. In the past few decades, dramatic technical advancements have led to the development of CT scanners that can be used to image virtually every structure within the human body. Improvements in scanner design and computer science have produced CT units with new imaging capabilities and reconstruction techniques. Three-dimensional reconstruction of images of the internal structures is becoming a popular choice for surgical planning, CT angiography, radiation therapy planning, and virtual reality.

CT-guided biopsies and fluid drainage offer an alternative to surgery for some patients. Although the procedures are considered invasive, they offer shorter recovery periods, no exposure to anesthesia, and less risk of infection. CT is also used in radiation oncology for radiation therapy planning. CT scans taken through the treatment field, with the patient in treatment position, have drastically improved the accuracy and quality of radiation therapy.

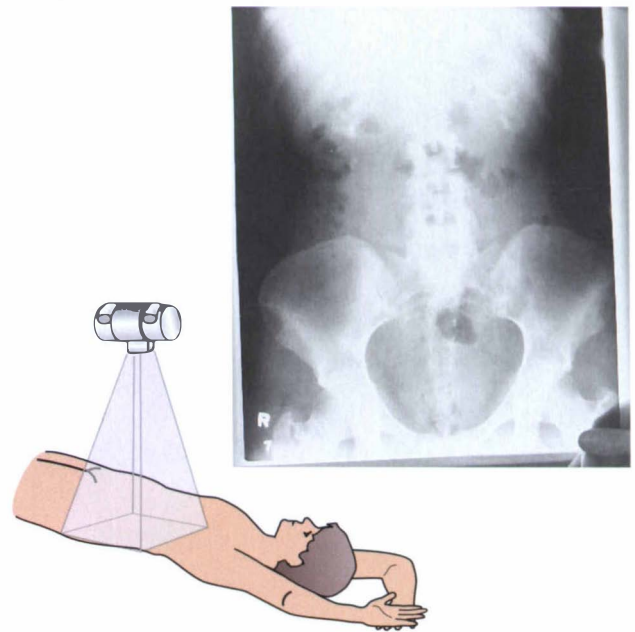
## Computed Tomography and Conventional Radiography

When a conventional x-ray exposure is made, the radiation passes through the patient and produces an image of the body part. Frequently body structures are superimposed (Fig. 33-2). Visualizing specific structures requires the use of contrast media, varied positions, and usually more than one exposure. Localization of masses or foreign bodies requires at least two exposures and a ruler calibrated for magnification.

In the CT examination, a tightly collimated x-ray beam is directed through the patient from many different angles, resulting in an image that represents a cross section of the area scanned. This imaging technique essentially eliminates the superimposition of body structures. The CT technologist controls the method of acquisition, the slice thickness, the reconstruction algorithm, and other factors related to image quality.



**Fig. 33-1** CT scanner provides cross-sectional images by rotating about the patient.



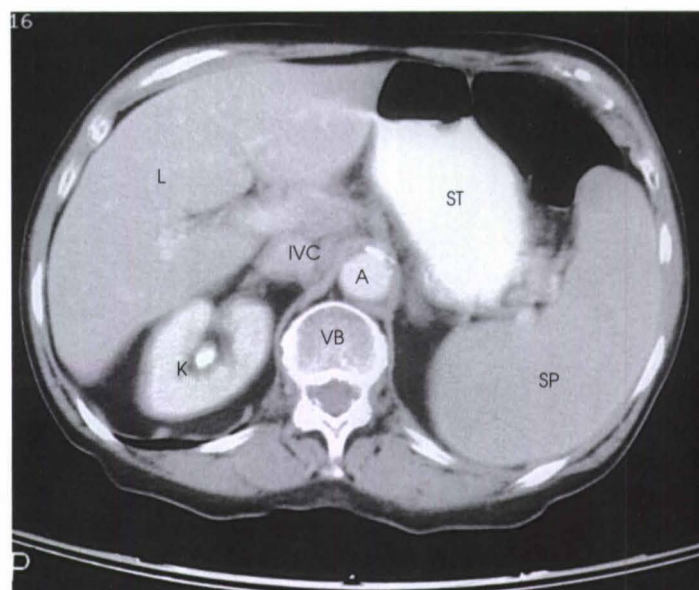
**Fig. 33-2** Conventional radiograph superimposes anatomy and yields one diagnostic image with fixed density and contrast.

In the digital radiograph of the abdomen shown in Fig. 33-3, high-density bone and low-density gas are seen, but many soft tissue structures, such as the kidneys and intestines, are not clearly identified. Contrast media are needed to visualize these structures. A CT examination of the abdomen would demonstrate all the structures that lie within the slice. In Fig. 33-4, A, the liver, stomach, kidneys, spleen, and aorta can be identified. In addition to eliminating superimposition, CT is capable of differentiating among tissues with similar densities. This differentiation of densities is referred to as contrast resolution. The improved *contrast resolution* with CT, when compared to conventional radiography, is due to a reduction in the amount of scattered radiation.

Fig. 33-4, B, is an axial image of the brain that differentiates the gray matter from the white matter and also shows bony structures and cerebrospinal fluid within the ventricles. Because CT can demonstrate subtle differences in various tissues, radiologists are able to diagnose pathologic conditions more accurately than if they were to rely on radiographs alone. Furthermore, because the image is digitized by the computer, numerous image manipulation techniques can be used to enhance and optimize the diagnostic information available to the physician (Fig. 33-5).



Fig. 33-3 Digital kidney, ureter, and bladder (KUB).



A

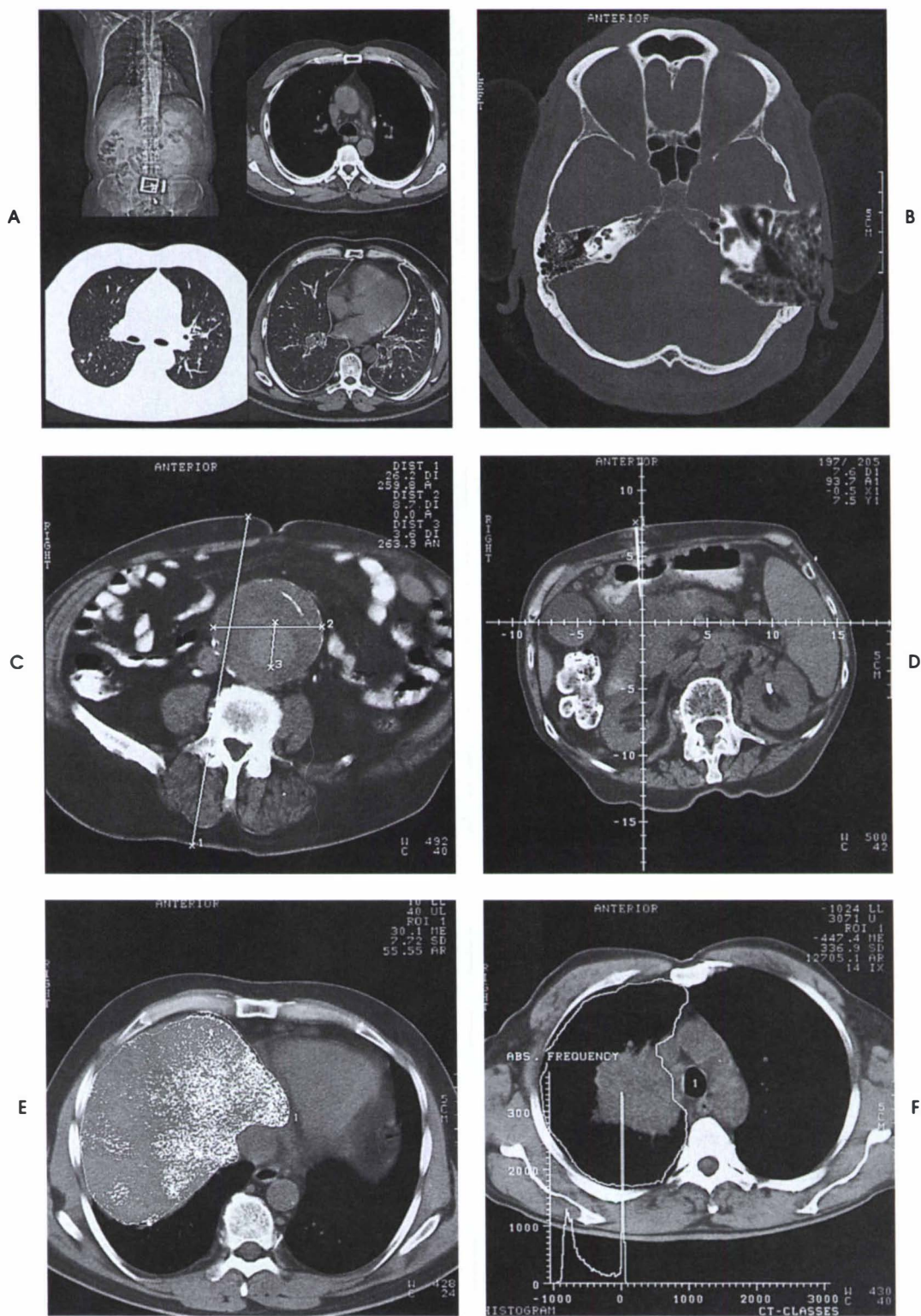


B

Fig. 33-4 A, Axial image of abdomen demonstrating liver (L), stomach (ST), spleen (SP), aorta (A), inferior vena cava (IVC), vertebral body of thoracic spine (VB), and kidney (K). B, Axial CT scan of lateral ventricles (LVah), septum (Sep), and third ventricle (3V).

(B, From Kelly LL, Peterson CM: *Sectional anatomy for imaging professionals*. St Louis, 1997, Mosby.)





**Fig. 33-5** Image manipulation techniques used to enhance diagnostic information in a CT image. **A**, multiple imaging and windows; **B**, image magnification; **C**, measurement of distances; **D**, superimposition of coordinates on the image; **E**, highlighting; and **F**, histogram.

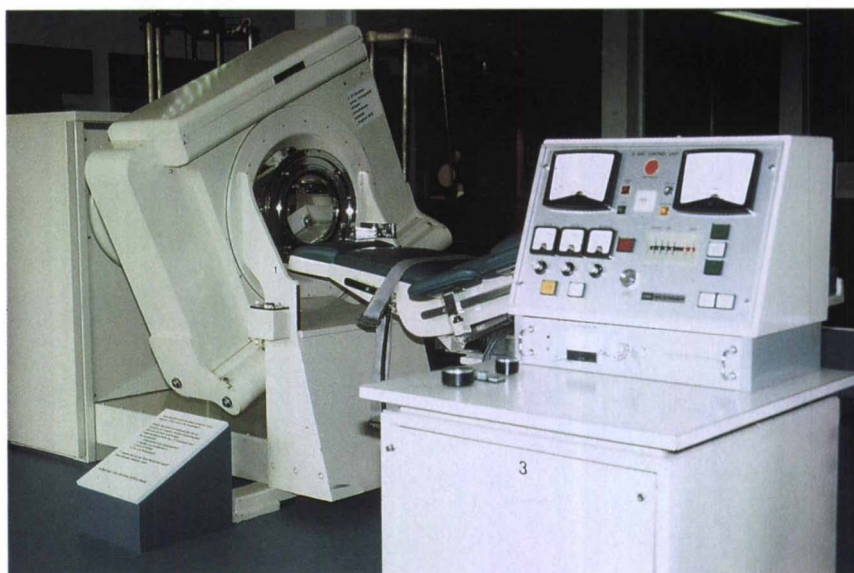
(Courtesy Siemens Medical Systems, Iselin, NJ.)



## Historical Development

CT was first demonstrated successfully in 1970 in England at the Central Research Laboratory of EMI, Ltd. Dr. Godfrey Hounsfield, an engineer for EMI, and Allan Macleod Cormack, nuclear physicist from Johannesburg, South Africa, are generally given credit for the development of CT. For their research they were awarded the Nobel Prize in medicine and physiology in 1979. After CT was shown to be a useful clinical imaging modality, the first full-scale commercial unit, referred to as a *brain tissue scanner*, was installed in Atkinson Morley's Hospital in 1971. An example of an early dedicated head CT scanner is shown in Fig. 33-6. Physicians recognized its value for providing diagnostic neurologic information, and its use was accepted rapidly. The first CT scanners in the United States were installed in June 1973 at the Mayo Clinic, Rochester, Minn., and later that year at Massachusetts General Hospital, Boston. These early units were also dedicated head CT scanners. In 1974, Dr. Robert S. Ledley of Georgetown University Medical Center, Washington, D.C., developed the first whole-body scanner, which greatly expanded the diagnostic capabilities of CT.

After CT was accepted by physicians as a diagnostic modality, numerous companies in addition to EMI began manufacturing scanners. Although the units differed in the design, the basic principles of operation were the same. CT scanners have been categorized by *generation*, which is a reference to the level of technologic advancement of the tube and detector assembly. There were four recognized generations of CT scanners; however, newer scanners are no longer categorized by generation but by tube and detector movement.

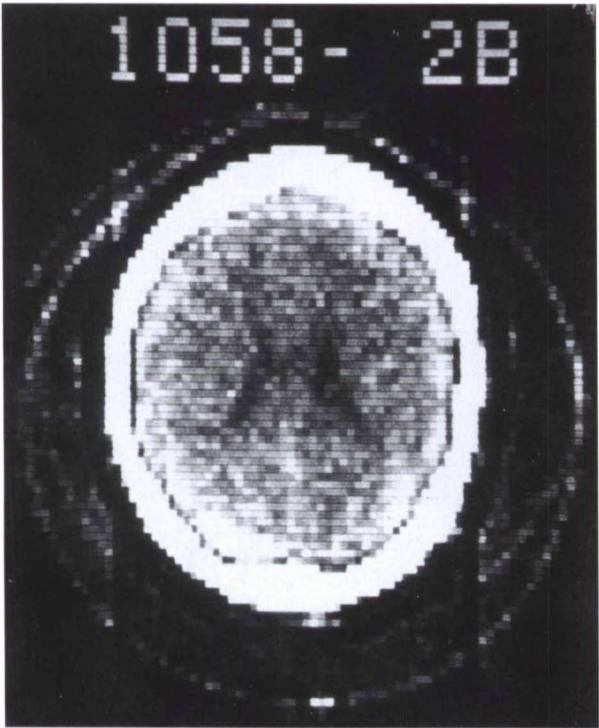


**Fig. 33-6** First-generation EMI CT unit: dedicated head scanner. Photograph taken at Röntgen Museum, Lennep, Germany.

The early units, referred to as the *first-generation scanners*, worked by a process known as *translation/rotation*. The tube produced a finely collimated beam, or pencil beam. Depending on the manufacturer, one to three *detectors* were placed opposite the tube for radiation detection. The linear tube movement (translation) was followed by a rotation of 1 degree. Scan time was usually 3 to 5 minutes per scan, which required the patient to hold still for extended periods. Because of the slow scanning and reconstruction time, the use of CT was limited almost exclusively to neurologic examinations. A CT image from a first-generation scanner is shown in Fig. 33-7.

The second-generation scanners were considered a significant improvement over first-generation scanners. The x-ray tube now emitted a fan-shaped beam that was measured by approximately 30 detectors placed closely together in a detector array. All subsequent generations would use the fan beam geometry. Tube and detector movement was still translation/rotation, but the rotation was 10 degrees between each translation. These changes improved overall image quality and decreased scan time to about 20 seconds for a single slice. However, the time required to complete one CT examination remained relatively long.

The *third generation* of scanners introduced a *rotate/rotate movement* in which both the x-ray tube and detector array rotate simultaneously around the patient. An increase in the number of detectors (over 750) and their arrangement in a “curved” detector array considerably improved image quality (Fig. 33-8). Scan times were decreased to 1 to 10 seconds per slice, which made the CT examination much easier for patients and helped to decrease motion artifact. Advancements in computer technology also decreased image reconstruction time, substantially reducing examination time.



**Fig. 33-7** Axial brain image from the first CT scanner in operation in the United States: Mayo Clinic, Rochester, Minn. The 80 × 80 matrix produced a noisy image. The examination was performed in July 1973.

The fourth-generation scanners introduced the *rotate-only movement* in which the tube rotated about the patient, but the detectors were in fixed positions, forming a complete circle within the gantry (Fig. 33-9). The use of stationary detectors required greater numbers of detectors to be installed in a scanner. Fourth-generation scanners tended to yield a higher patient dose per scan than previous generations of CT scanners.

In contemporary CT scanners, both third- and fourth-generation designs incorporate the latest technologic advances and produce similar image quality.

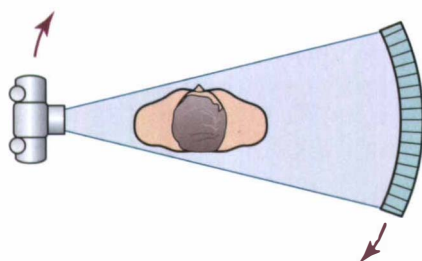


Fig. 33-8 Rotate/rotate movement: tube and detector movement of a third-generation scanner.

## Technical Aspects

The axial images acquired by CT scanning provide information about the positional relationships and tissue characteristics of structures within the section of interest. The computer performs a series of steps to generate one axial image. With the patient and gantry perpendicular to each other the tube rotates around the patient, irradiating the area of interest. For every position of the x-ray tube, the detectors measure the transmitted x-ray values, convert them into an electric signal, and relay the signal to the computer. The measured x-ray transmission values are called *projections (scan profiles)* or *raw data*. Once collected, the electrical signals are digitized, a process that assigns a whole number to each signal. The value of each number is directly proportional to the strength of the signal.

The digital image is an array of numbers arranged in a grid of rows and columns called a *matrix*. A single square, or picture element, within the matrix is called a *pixel*. The slice thickness gives the pixel an added dimension called the *volume element*, or *voxel*. Each pixel in the image corresponds to the volume of tissue in the body section being imaged. The voxel volume is a product of the pixel area and slice thickness (Fig. 33-10). The *field of view (FOV)* determines the amount of data to be displayed on the monitor.

Each pixel within the matrix is assigned a number that is related to the linear attenuation coefficient of the tissue within each voxel. These numbers are called *CT numbers* or *Hounsfield units*. CT numbers are defined as a relative comparison of x-ray attenuation of a voxel of tissue to an equal volume of water. Water is used as reference material because it is abundant in the body and has a uniform density; therefore water is assigned an arbitrary value of 0. Tissues that are denser than water are given positive CT numbers, whereas tissues with less density than water are assigned negative CT numbers. The scale of CT numbers ranges from -1000 for air to +14,000 for dense bone. Average CT numbers for various tissues are listed in Table 33-1.

For displaying the digital image on the CRT, each pixel within the image is assigned a level of gray. The gray level assigned to each pixel corresponds to the CT number for that pixel.

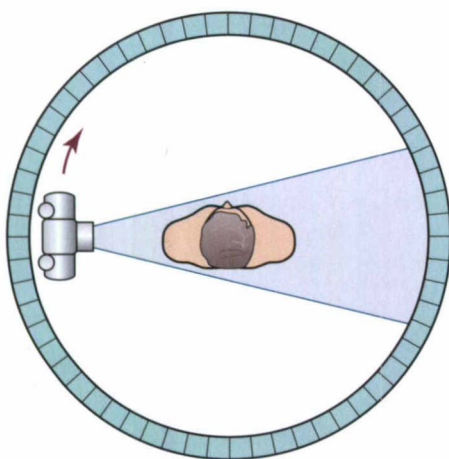


Fig. 33-9 Rotate-only movement: tube movement with stationary detectors of a fourth-generation scanner.

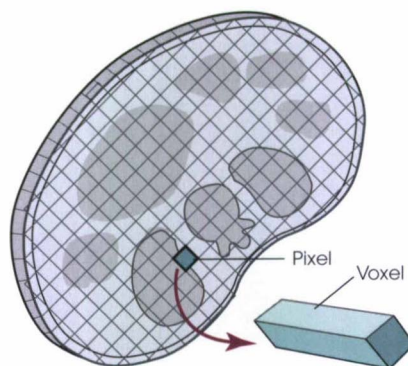


Fig. 33-10 A CT image is composed of a matrix of pixels, with each pixel representing a volume of tissue (voxel).

TABLE 33-1

Average Hounsfield units (HU) for selected substances

Substance	HU
Air	-1000
Lungs	-250 to -850
Fat	-100
Orbit	-25
Water	0
Cyst	-5 to +10
Fluid	0 to +25
Tumor	+25 to +100
Blood (fluid)	+20 to +50
Blood (clotted)	+50 to +75
Blood (old)	+10 to +15
Brain	+20 to +40
Muscle	+35 to +50
Gallbladder	+5 to +30
Liver	+40 to +70
Aorta	+35 to +50
Bone	+150 to +1000
Metal	+2000 to +4000



## System Components

The three major components of the CT scanner are shown in Fig. 3-11. Because each component has several subsystems, only a brief description of their main functions is provided in the following sections.

### COMPUTER

The computer provides the link between the CT technologist and the other components of the imaging system. The computer system used in CT has four basic functions: control of data acquisition, image reconstruction, storage of image data, and image display.

*Data acquisition* is the method in which the patient is scanned. The technologist must select among numerous parameters, such as scanning in the conventional or helical mode, before the initiation of each scan. During implementation of the *data acquisition system (DAS)*, the computer is involved in sequencing the generation of x-rays, turning the detectors on and off at appropriate intervals, transferring data, and monitoring the system operation.

The *reconstruction* of a CT image depends on the millions of mathematical operations required to digitize and reconstruct the raw data. This image reconstruction is accomplished using an array processor that acts as a specialized computer to perform mathematical calculations rapidly and efficiently, thus freeing the host computer for other activities. Currently, CT units can acquire scans in less than 1 second and require only a few seconds more for image reconstruction.

The *host computer* in CT has limited storage capacity so image data can be stored only temporarily. Therefore other storage mechanisms are necessary to allow for long-term *data storage and retrieval*. After reconstruction, the CT image data can be transferred to another storage medium such as magnetic tapes or optical disks. This allows CT studies to be removed from the limited memory of the host computer and stored independently, a process termed *archiving*.

The reconstructed images are displayed on a CRT or video monitor. At this point the technologist or physician can communicate with the host computer to view specific images, post images on a scout, and/or implement image manipulation techniques such as zoom, control contrast and brightness, and image analysis techniques.

### GANTRY AND TABLE

The *gantry* is a circular device that houses the x-ray tube, DAS, and detector array. Newer CT units also house the continuous *slip ring* and high-voltage generator in the gantry. The structures housed in the gantry collect the necessary attenuation measurements to be sent to the computer for image reconstruction.

The x-ray tube used in CT is similar in design to the tubes used in conventional radiography, but it is specially designed to handle and dissipate excessive heat units created during a CT examination. Most CT x-ray tubes use a rotating anode to increase heat dissipation. Many CT x-ray tubes can handle around 2.1 million heat units (MHU), whereas advanced CT units can tolerate 4 to 5 MHU.

The detectors in CT function as image receptors. A detector measures the amount of radiation transmitted through the body and then converts the measurement into an electrical signal proportional to the radiation intensity. The two basic detector types used in CT are scintillation (solid state) and ionization (xenon gas) detectors.

The gantry can be tilted forward or backward up to 30 degrees to compensate for body part angulation. The opening within the center of the gantry is termed the *aperture*. Most apertures are about 28 inches (71.1 cm) wide to accommodate a variety of patient sizes as the patient table advances through it.



**Fig. 33-11** Components of a CT scanner: 1, Computer and operator's console; 2, gantry; 3, patient table.

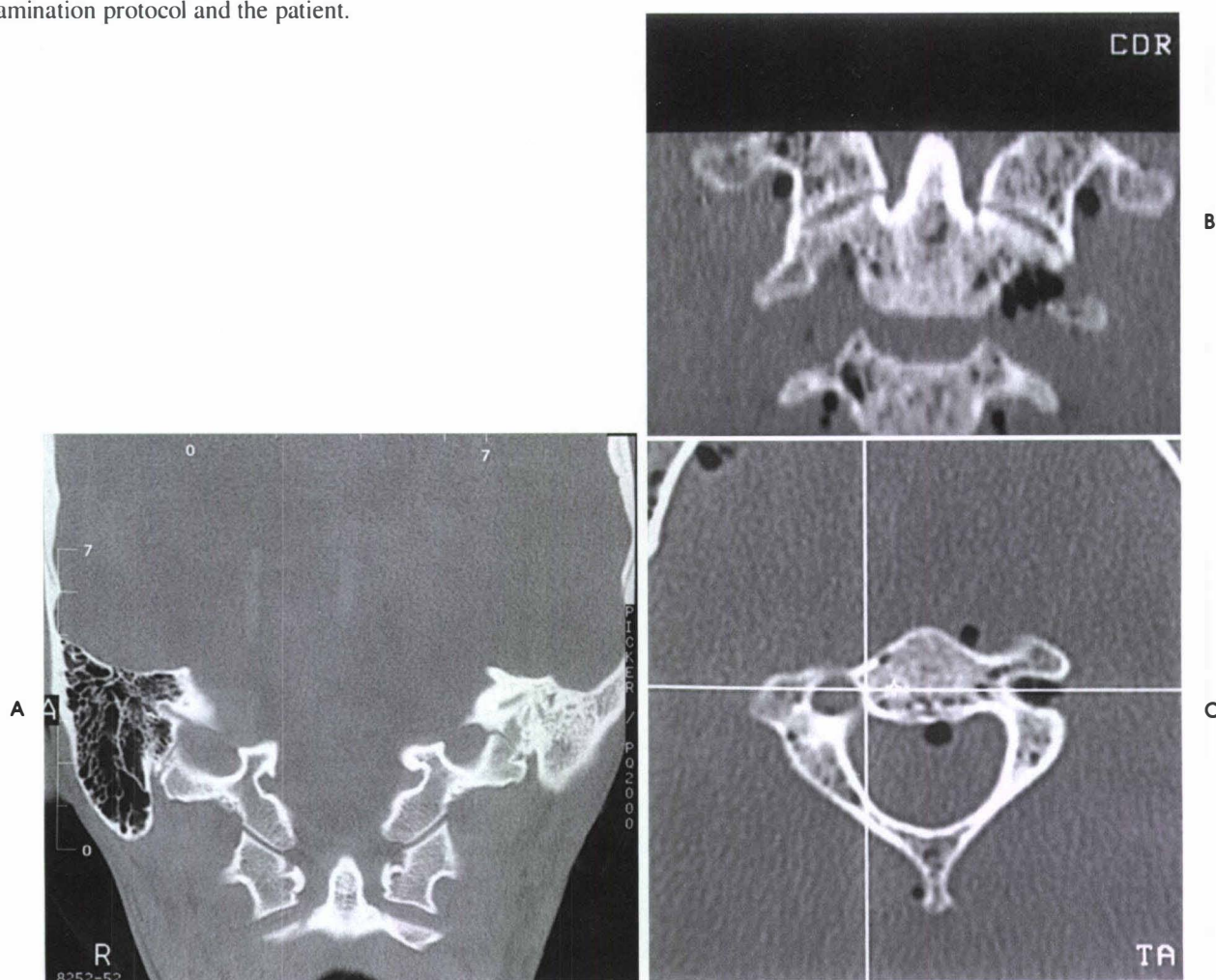
(Courtesy GE Medical Systems, Waukesha, Wisc.)

For certain head studies, such as those of facial bones, sinuses, or the sella turcica, a combination of patient positioning and gantry angulation results in a *direct coronal* image of the body part being scanned. Fig. 33-12, A, demonstrates a typical direct coronal image of C1 to C2. In comparison, a computer-reconstructed coronal image created from axial scans through the body part is shown in Fig. 33-12, B. Overall image resolution and quality are lost in the reconstructed image as compared with the direct coronal image.

The *table* is an automated device linked to the computer and gantry. It is designed to move in increments (*index*) after every scan according to the scan program. The table is an extremely important part of a CT scanner. Indexing must be accurate and reliable, especially when thin slices (1 or 2 mm) are taken through the area of interest. Most CT tables can be programmed to move in or out of the gantry, depending on the examination protocol and the patient.

CT tables are made of wood or low-density carbon composite, both of which support the patient without causing image artifacts. The table must be very strong and rigid to handle patient weight and at the same time maintain consistent indexing. All CT tables have a maximum patient weight limit; this limit varies by manufacturer from 300 to 600 lb (136 to 272 kg). Exceeding the weight limit can cause inaccurate indexing, damage to the table motor, and even possible breakage of the tabletop, which could cause serious injury to the patient.

Accessory devices can be attached to the table for a variety of uses. A special device called a *cradle* is used for head CT examinations. The head cradle helps to hold the head still; because the device extends beyond the tabletop, it minimizes artifacts or attenuation from the table while the brain is being scanned. It can also be used in positioning the patient for direct coronal images.



**Fig. 33-12** A, Direct coronal image of C1 to C2. B, Computed-reconstructed images of C1 to C2. C, Axial image for coronal reconstruction.

(Courtesy Siemens Medical Systems, Iselin, N.J.)



## OPERATOR'S CONSOLE

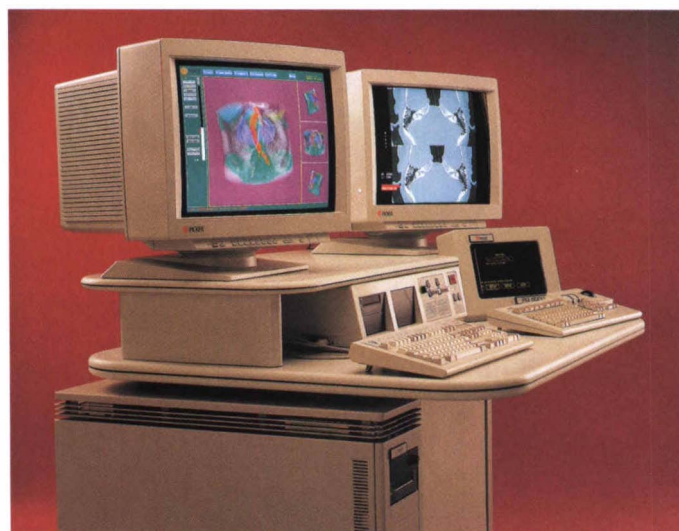
The *operator's console* (Fig. 33-13) is the point from which the technologist controls the scanner. A typical console is equipped with a keyboard for entering patient data and a graphic monitor for viewing the images. Other input devices, such as a touch display screen and a computer mouse, may also be used. The operator's console allows the technologist to control and monitor numerous scan parameters. Radiographic technique factors, slice thickness, table index, and reconstruction algorithm are some of the scan parameters that are selected at the operator's console.

Before starting an examination, the technologist must enter the patient information. Therefore a keyboard is still necessary for some functions. Usually the first scan program selected is the scout program from which the radiographer plans the sequence of axial scans. An example of a typical scout image is seen in Fig. 33-3. The operator's console is also the location of the CRT, where image manipulation takes place. Most scanners display the image on the CRT in a 1024 matrix interpolated by the computer from the 512 reconstructed images.

## OTHER COMPONENTS

### Display monitor

For the CT image to be displayed on a CRT monitor in a recognizable form, the digital CT data must be converted into a *gray-scale image*. This process is achieved by the conversion of each digital CT number in the matrix to an analog voltage. The brightness values of the gray-scale image correspond to the pixels and CT numbers of the digital data they represent.



**Fig. 33-13** Console with display monitors, keyboards, and workstation for three-dimensional image manipulation.

(Courtesy, Marconi Medical Systems, Inc. Highland Heights, Ohio.)



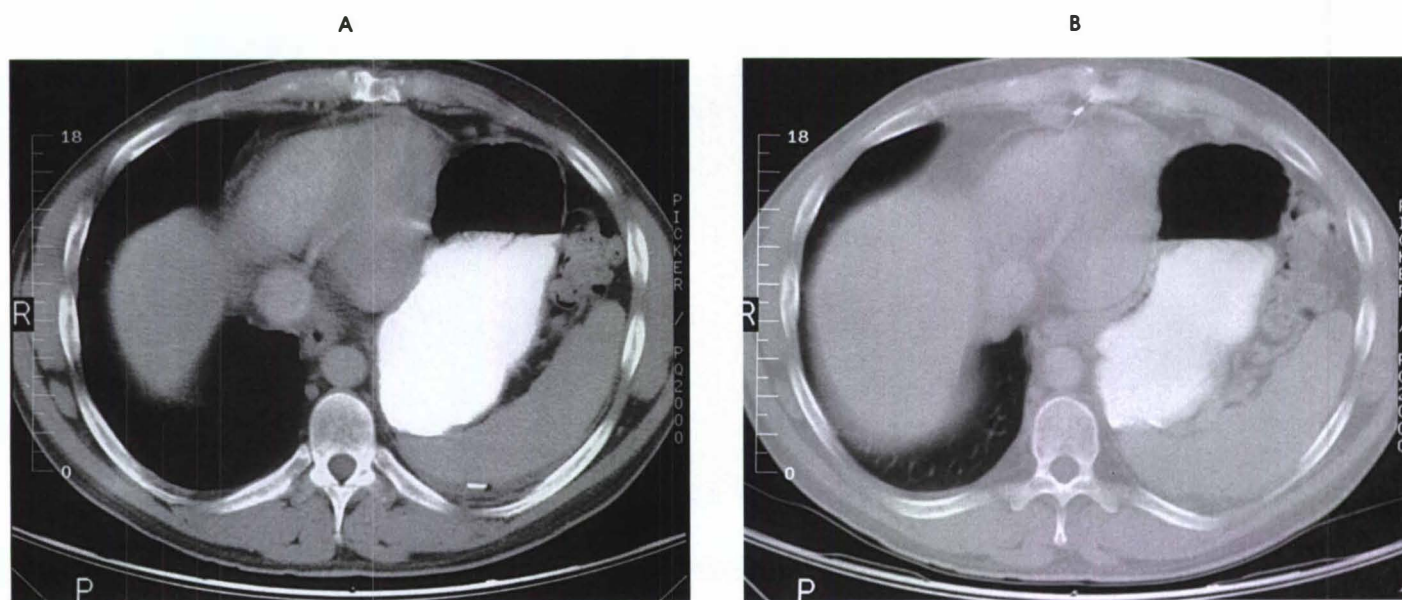
Because of the digital nature of the CT image data, image manipulation can be performed to enhance the appearance of the image. One of the most common image processing techniques is called *windowing*, or *gray-level mapping*. This technique allows the technologist to alter the contrast of the displayed image by adjusting the window width and window level. The *window width* is the range of CT numbers that are used to map signals into shades of gray. Basically, the window width determines the number of gray levels to be displayed in the image. A narrow window width means that there are fewer shades of gray, resulting in higher contrast. Likewise, a wide window width results in more shades of gray in the image, or a longer gray scale. The *window level* determines the midpoint of the range of gray levels to be displayed on the monitor. It is used to set the center CT number within the range of gray levels being used to display the image. The window level should be set to the CT number of the tissue of interest, and the window width should be set with a range of values that will optimize the contrast between the tissues in the image. Fig. 33-14 shows an axial image seen in two different windows: a standard abdomen window and a bone window adjusted for the spine.

The gray level of any image can be adjusted on the CRT to compensate for differences in patient size and tissue densities or to display the image as desired for the examination protocol. Examples of typical window width and level settings are listed in Table 33-2. These settings are averages and usually vary by machine. It is important to note that the level, although an average, is approximately the same as the CT numbers expected for the tissue densities.

**TABLE 33-2**

Typical window settings

CT examination	Width	Center (level)
Brain	190	50
Skull	3500	500
Orbits	1200	50
Abdomen	400	35
Liver	175	45
Mediastinum	325	50
Lung	2000	-500
Spinal cord	400	50
Spine	2200	400



**Fig. 33-14** **A**, Abdominal image, soft tissue window. **B**, Abdominal image: bone window.

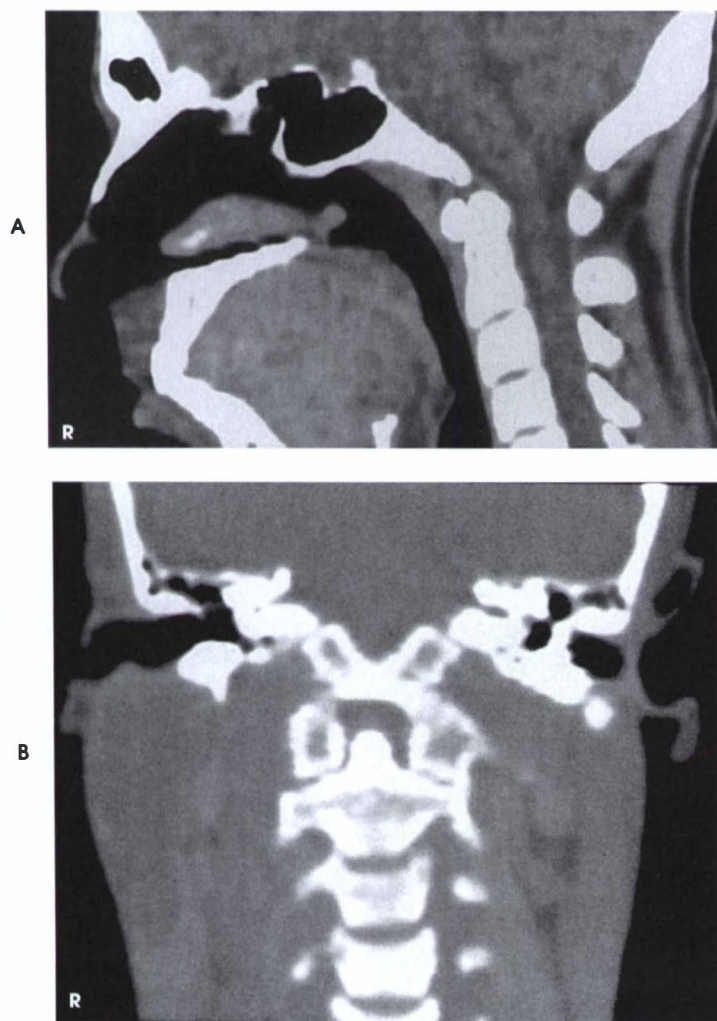
### Multiplanar reconstruction

Another advantage of the digital nature of the CT image is the ability to reconstruct the axial images into coronal, sagittal, or oblique body planes without additional radiation to the patient. Image reconstruction in a variety of planes is accomplished by stacking multiple contiguous axial images, creating a volume of data. Because the CT numbers of the image data within the volume are already known, a sectional image can be generated in any desired plane by selecting a particular plane of data. This postprocessing technique is termed *multiplanar reconstruction (MPR)*. A sagittal reconstruction of data obtained from axial images is shown in Fig. 33-15, A. A coronal reconstruction is seen in Fig. 33-15, B.

One of the most important functions of the operator's console is to produce hard copies of axial images in the form of film. The most commonly used filming devices are the matrix camera and the laser printer. The matrix camera once was the standard imaging device used in CT. Now the laser printer is the preferred device for imaging, and it should be docked directly to a processor whenever possible.

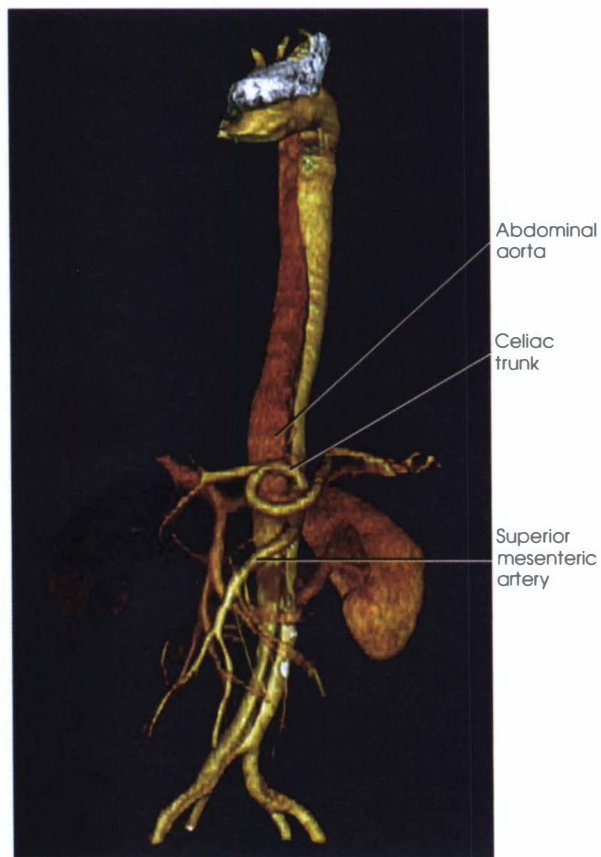
### Diagnostic Applications

The original CT studies were used primarily for diagnosing neurologic disorders. As scanner technology advanced, the range of applications was extended to other areas of the body. The most commonly requested procedures involve the head, chest, and abdomen. CT is the examination of choice for head trauma; it clearly demonstrates skull fractures and associated subdural hematomas. CT imaging of the central nervous system can demonstrate infarctions, hemorrhage, disk herniations, craniofacial and spinal fractures, and tumors and other cancers. CT imaging of the body excels at demonstrating soft tissue structures within the chest, abdomen, and pelvis. Among the abnormalities demonstrated in this region are metastatic lesions, aneurysms, abscesses, and fluid collections from blunt trauma (Fig. 33-16).



**Fig. 33-15** A, Computer-reconstructed sagittal image. B, Computer-reconstructed coronal image.

(Courtesy Siemens Medical Systems, Iselin, N.J.)

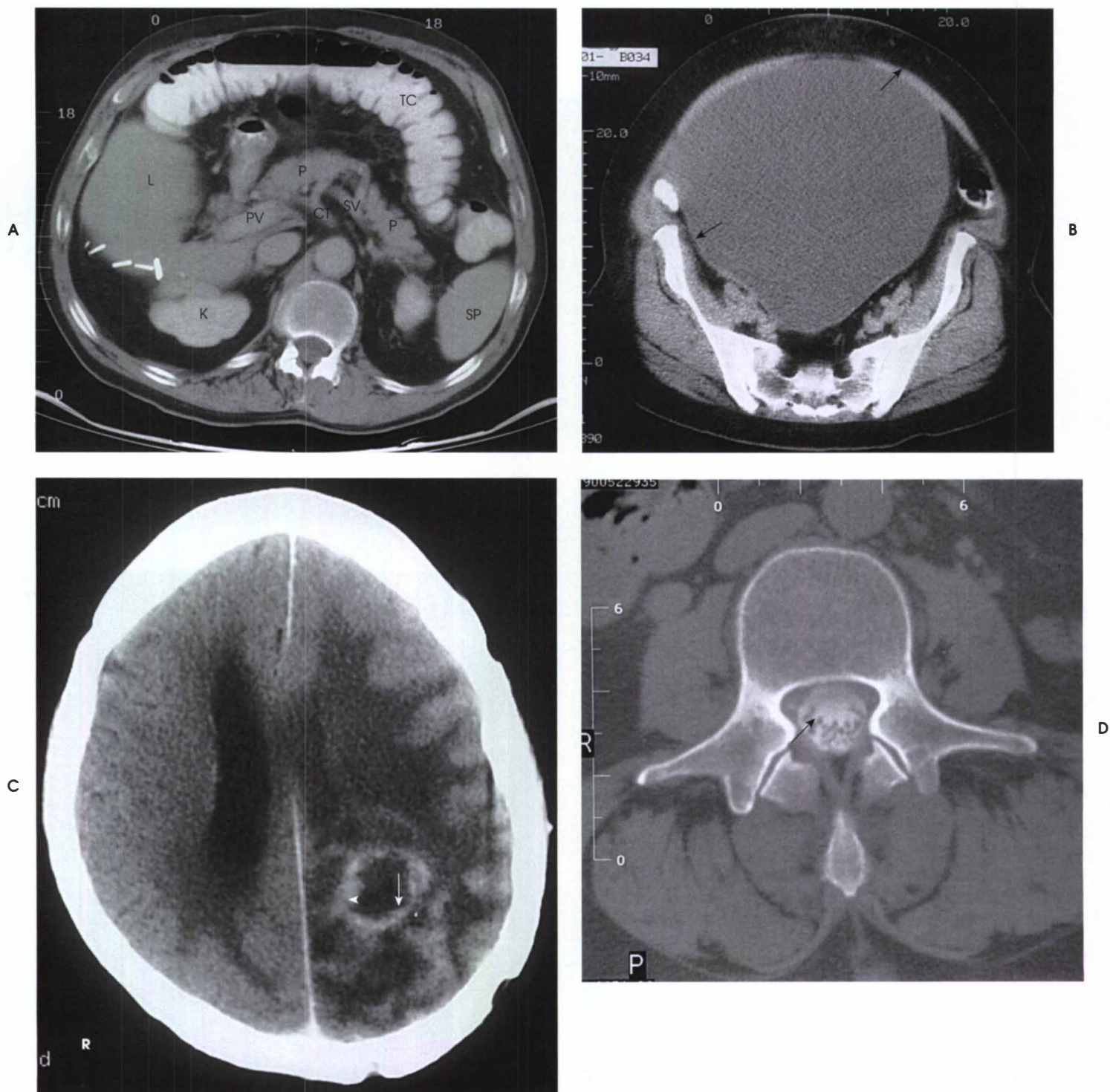


**Fig. 33-16** Aortic dissection in color, 3D rendered.



CT is also used for numerous interventional procedures such as abscess drainage, tissue biopsy, and cyst aspiration. Fig. 33-17 demonstrates a number of structures and pathologic conditions identified by CT.

For any procedure a protocol is required to maximize the amount of diagnostic information available. Specific examination protocols vary according to the needs of different medical facilities and physicians.



**Fig. 33-17** **A**, Abdominal image demonstrating transverse colon (TC) with air-fluid levels; the liver (L), pancreas (P), spleen (SP), kidney (K), portal vein (PV), celiac trunk (CT), and splenic veins (SV) are demonstrated with contrast medium. Surgical clips are seen in posterior liver. **B**, Abdominal image demonstrating extremely large ovarian cyst (arrows). **C**, Brain image demonstrating parietooccipital mass (arrow) with characteristic IV contrast ring enhancement (arrowhead). **D**, Image of L3 postmyelogram demonstrating contrast in thecal sac (arrow).



## Contrast Media

Contrast media is used in CT examinations to help distinguish normal anatomy from pathology and to make various disease processes more visible. Contrast can be administered intravenously, orally, or rectally. Generally, the IV contrast media are the same as those used for excretory urograms. Many facilities use nonionic contrast material for these studies, despite the relatively high cost, because of the low incidence of reaction and known safety factors associated with nonionic contrast. IV contrast media are useful for demonstrating tumors within the head; Fig. 33-18 shows a brain scan with and without contrast. The anterior lesion is evident in the unenhanced scan; in the enhanced scan, the tumor demonstrates characteristic ring enhancement typical of tumors seen in CT scans. IV contrast media is also used to visualize vascular structures in the body.

IV contrast should be used only with approval of the radiologist and after careful consideration of patient history. Many CT examinations can be performed without IV contrast if necessary; however, the amount of diagnostic information available can be limited.

Oral contrast media must be used for imaging the abdomen. When given orally, the contrast material in the gastrointestinal tract helps to differentiate between loops of bowel and other structures within the abdomen. An oral contrast medium is generally a 2% barium mixture. The low concentration prevents contrast artifacts but allows good visualization of the stomach and intestinal tract. An iodinated contrast material such as oral Hypaque can be used, but it must be mixed at low concentrations to prevent contrast artifacts. Rectal contrast is often requested as part of an abdominal or pelvic protocol. Usually mixed in the same concentration as the oral contrast, the rectal contrast material is useful for demonstrating the distal colon relative to the bladder and other structures of the pelvic cavity.

## Factors Affecting Image Quality

In CT the technologist has access to numerous scan parameters that can have a dramatic effect on image quality. The four main factors contributing to image quality are spatial resolution, contrast resolution, noise, and artifacts.

### SPATIAL RESOLUTION

*Spatial resolution* describes the amount of blurring in an image. The scan parameters that affect spatial resolution include focal spot size, slice thickness, display FOV, matrix, and reconstruction algorithm. The detector aperture width is the most significant geometric factor that contributes to spatial resolution. The spatial resolution in CT is not as good as in conventional radiography.

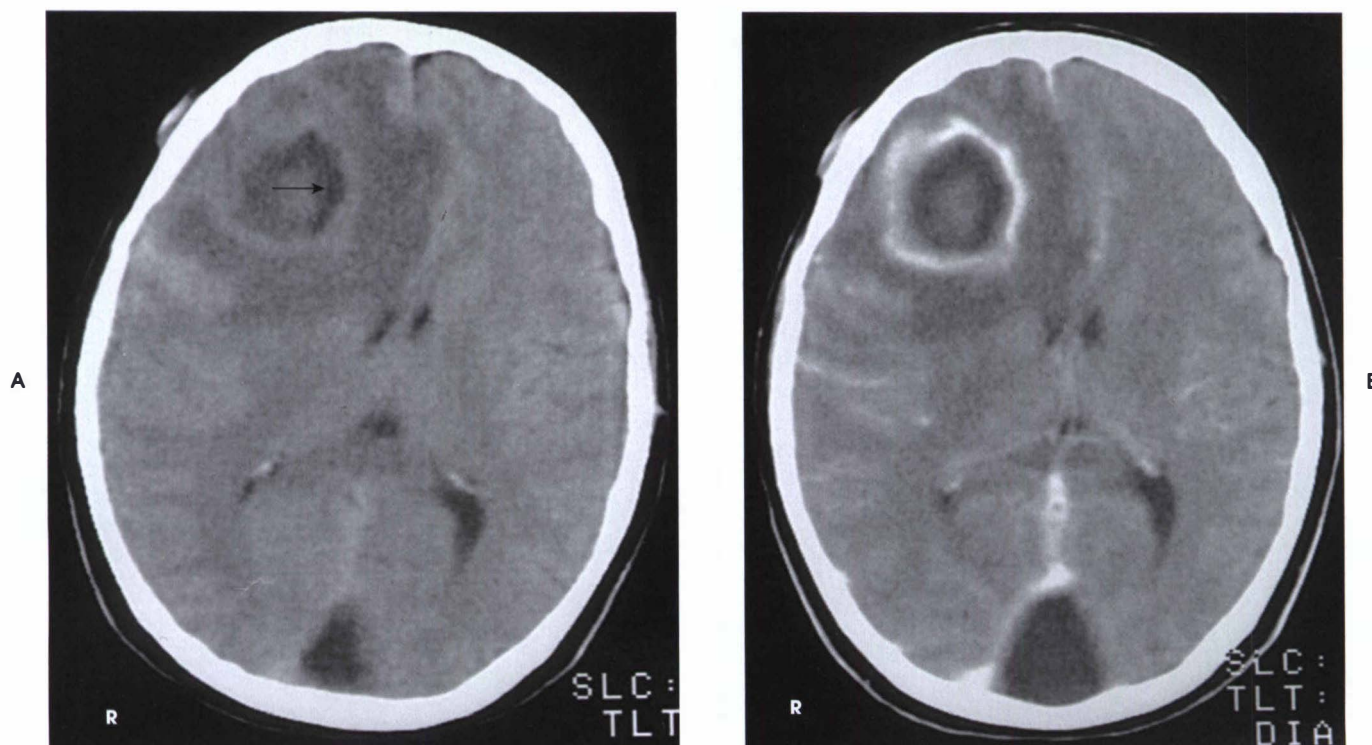


Fig. 33-18 **A**, Brain image without IV contrast demonstrating lesion (arrow). **B**, Brain image with IV contrast.

## CONTRAST RESOLUTION

*Contrast resolution* is the ability to differentiate between small differences in density within the image. Currently, tissues with density differences of less than 0.5% can be distinguished with CT. The scan parameters that affect contrast resolution are slice thickness, reconstruction algorithm, image display, and x-ray beam energy. The size of the patient and the detector sensitivity also have a direct effect on contrast resolution.

## NOISE

The most common cause of *noise* in CT is *quantum noise*. This type of noise arises from the random variation in photon detection. Noise in a CT image primarily affects contrast resolution. As noise increases in an image, contrast resolution decreases. Noise gives an image a grainy quality or a mottled appearance. Among the scan parameters that influence noise are matrix size, slice thickness, x-ray beam energy, and reconstruction algorithm. Scattered radiation and patient size also contribute to the noise of an image.

## ARTIFACTS

Metallic objects, such as dental fillings, pacemakers, and artificial joints, can cause starburst or *streak artifacts*, which can obscure diagnostic information. Dense residual barium from fluoroscopy examinations can cause *artifacts* similar to those caused by metallic objects. Many CT departments do not perform a patient's CT examination until several days after barium studies to allow the body to eliminate the residual barium from the area of interest. Large differences in tissue densities of adjoining structures can cause artifacts that detract from image quality. Bone-soft-tissue interfaces, such as occur with the skull and brain, often cause streak or shadow artifacts on CT images; these artifacts are referred to as *beam hardening* (Fig. 33-19).

## OTHER FACTORS

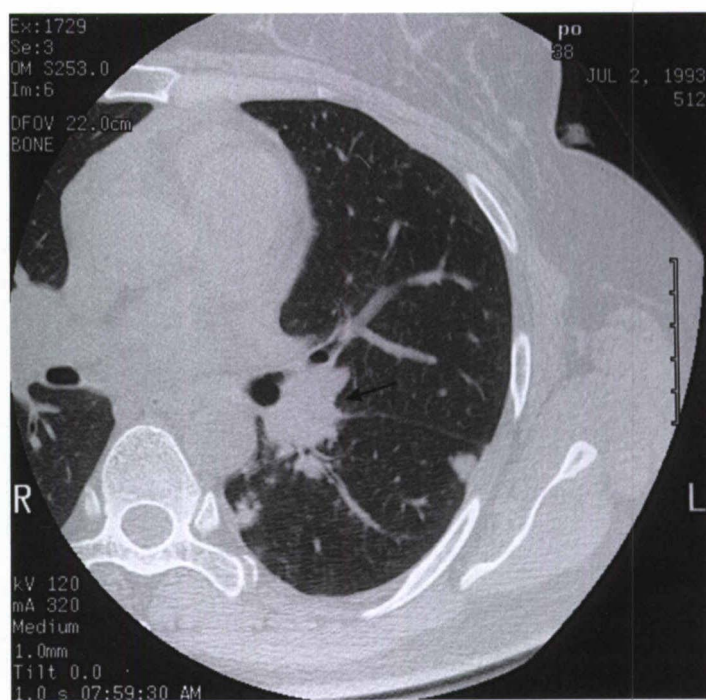
### Patient factors

Patient factors also contribute to the quality of an image. If a patient cannot or will not hold still, the scan will likely be non-diagnostic. Body size also can have an effect on image quality. Large patients attenuate more radiation than small patients; this can increase image noise, detracting from overall image quality. An increase in milliamperere-seconds (mAs) is usually required to compensate for large body size. Unfortunately, this increase results in a higher radiation dose to the patient. Image quality factors under technologist control include slice thickness, *scan time*, *scan diameter*; and patient instructions. Slice thickness is usually dictated by image *protocol*. As in tomography, the thinner the slice thickness, the better the image-recorded detail. Thin-section CT scans, often referred to as *high-resolution scans*, are used to better demonstrate structures (Fig. 33-20).

As in conventional radiography, patient instructions are a critical part of a diagnostic examination. Explaining the procedure fully in terms the patient can understand will increase the level of compliance from almost any patient.



**Fig. 33-19** Streaking through the posterior fossa representing beam hardening artifact. Normal appearance of the brain; 1, sphenoidal sinus; 2, trigeminal ganglion; 3, fourth ventricle; 4, temporal lobe; 5, pons; 6, middle cerebellar peduncle; 7, cerebellar hemisphere.



**Fig. 33-20** High-resolution 1-mm slice using edge enhancement algorithm, demonstrating nodule in left lung (arrow).



### Scan times

Scan times are usually preselected by the computer as part of the scan program, but they can be altered by the technologist. When selecting a scan time, the technologist must take into account possible patient motion such as inadvertent body movements, breathing, or peristalsis. A good guideline is to choose a scan time that will minimize patient motion and at the same time provide a quality diagnostic image. When it is necessary to scan an uncooperative patient quickly, using the shortest scan time possible may allow the technologist to complete the examination although the quality of the images obtained will likely be somewhat compromised.

### Scan diameter

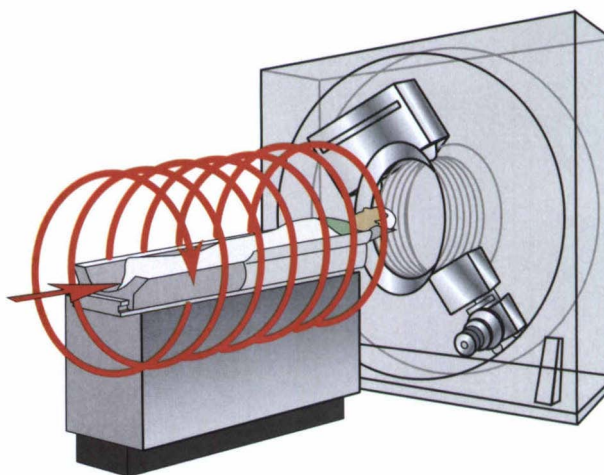
The image that appears on the CRT depends on the *scan diameter* also called scan FOV. The technologist can adjust the scan diameter to include the entire cross section of the body part being scanned or to include only a specified region within the part. The anatomy displayed is often referred to as the display FOV. Like scan time, scan diameter is usually preselected by the computer as part of a scan program, but it can also be adjusted as necessary by the technologist. For most head, chest, and abdomen examinations the selected scan diameter includes all anatomy of the body part to just outside the skin borders. Certain examinations may require the scan diameter to be reduced to include specific anatomy such as the sella turcica, sinuses, one lung, mediastinal vessels, suprarenal glands, one kidney, or the prostate.

## Special Features

### DYNAMIC SCANNING

One of the advantages of CT is that data can be obtained for image reconstruction by the computer. The scanner can be programmed to scan through an area rapidly. In this situation raw data are saved, but image reconstruction after each scan is bypassed to shorten scan time.

*Dynamic scanning* is based on the principle that after contrast administration, different structures enhance at different rates. Dynamic scanning can consist of rapid sequential scanning at the same level to observe contrast filling within a structure, such as is performed when looking for an aortic aneurysm. Another form of dynamic scanning is incremental dynamic scanning, which consists of rapid serial scanning at consecutive levels during the bolus injection of a contrast medium.



**Fig. 33-21** Continuous gantry rotation combined with continuous table rotation forming a spiral path of data.

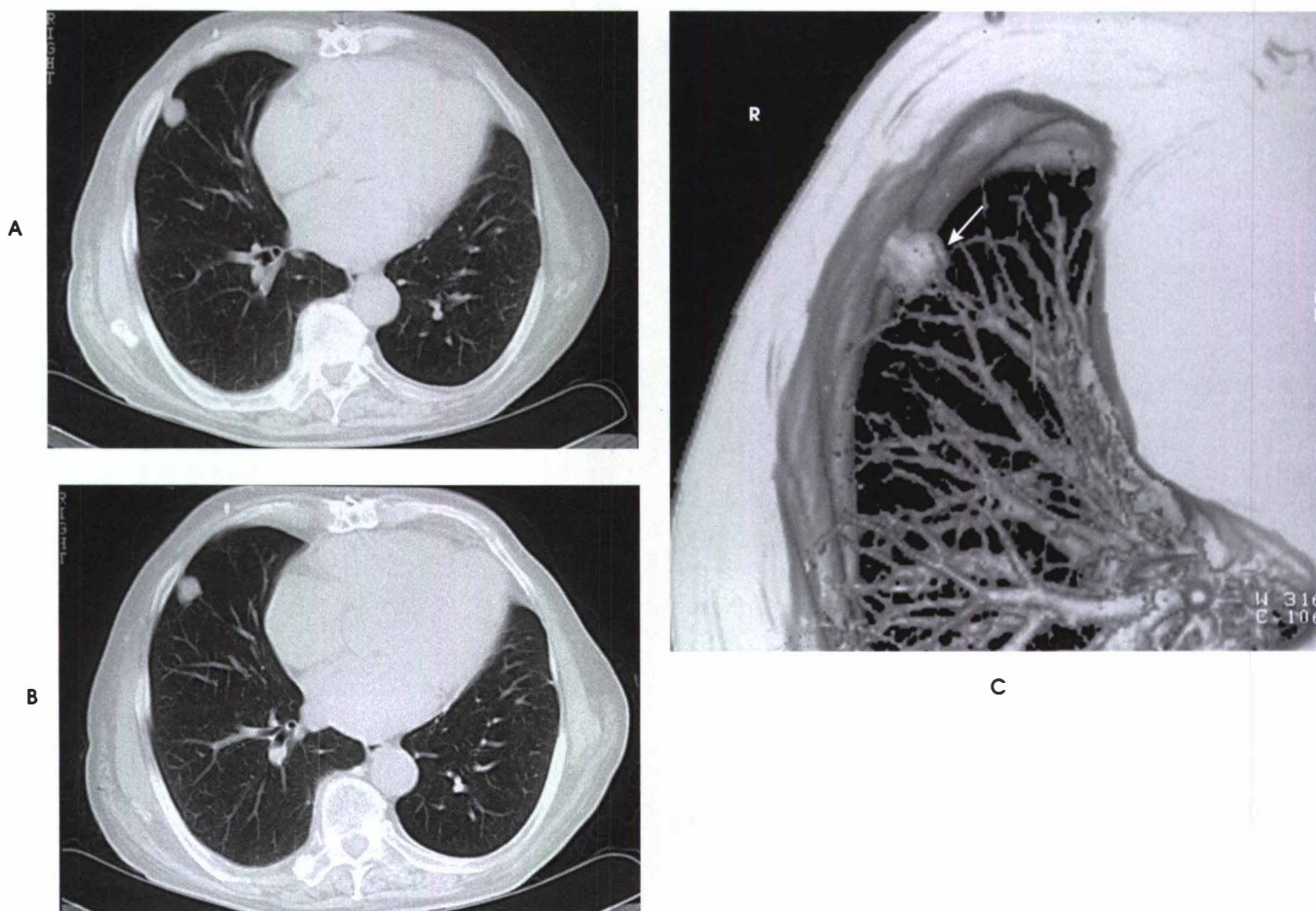


### SPIRAL/HELICAL CT

*Spiral CT* or *helical CT* are terms used to describe the newest method of data acquisition in CT. During spiral CT, the gantry is rotating continuously while the table moves through the gantry aperture at the same time. The continuous gantry rotation combined with the continuous table movement forms the spiral path from which raw data are obtained Fig. 33-21. Slip-ring technology has made continuous rotation of the x-ray tube possible by eliminating the cables between the gantry and the generators.

One of the unique features of spiral CT is that it scans a volume of tissue rather than a group of individual slices. This method makes it extremely useful for the detection of small lesions because an arbitrary slice can be reconstructed along any position within the volume of raw data. In addition, because a volume of tissue is scanned in a single breath, respiratory motion can be minimized. For a volume scan of the chest such as that shown in Fig. 33-22, the patient was instructed to hold their breath and a tissue volume of 24 mm was obtained in a 5-second spiral scan.

Two of the resultant images demonstrate a small lung nodule without breathing interference of *image misregistration*; a three-dimensional reconstruction of the lung clearly shows the pathologic condition. Spiral CT is also used to scan noncooperative or combative patients, patients who cannot tolerate lying down for long periods of time, and patients who will not hold still, such as pediatric patients or trauma patients. In some examinations, the use of spiral CT may decrease the amount of contrast medium necessary to visualize structures; this makes the examination both safer and more cost-effective.



**Fig. 33-22** **A** and **B**, Spiral images of lung demonstrating lung nodule and associated vasculature. **C**, Three-dimensional reconstruction of lung nodule (arrow) after spiral scan.

(Courtesy Siemens Medical Systems, Iselin, N.J.)

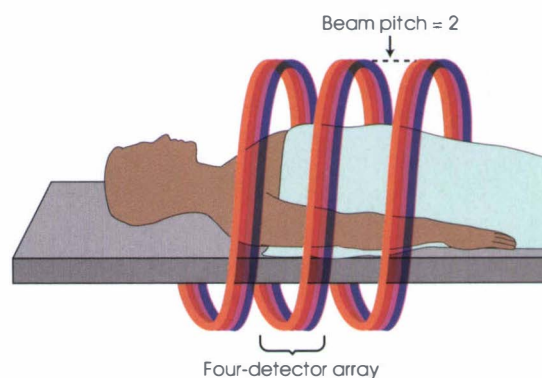
### MULTI-SLICE SPIRAL/HELICAL CT

The latest technologic advancement in CT is the development of scanners that are capable of scanning multiple images during one gantry rotation. *Multi-slice helical CT (MSHCT)* systems have detectors arrays containing multiple rows of elements along the z axis compared to the single row of detectors in conventional spiral CT (Fig. 33-23). In a "quad-section" scanner, the detector array is connected to four data acquisition systems that generate four channels of data. To collect four slices of data at the same time a minimum of four detectors, placed side by side along the z axis, are necessary. More than four detector elements are required when several choices of slice thickness are desired. The advantages of MSHCT include: isotropic viewing, longer anatomic coverage, multiphase studies, faster examination times, and improved spatial resolution. This new CT technology promises to provide new and unique clinical opportunities in diagnostic medicine.

### CT ANGIOGRAPHY

*CT angiography (CTA)* is a relatively new application of spiral CT that uses three-dimensional (3D) imaging techniques. With CTA the vascular system can be viewed in three dimensions. The three basic steps required to generate CTA images are as follows:

1. Choice of parameters for IV administration of the *bolus* of contrast medium (i.e., injection rate, injection duration, and delay between bolus initiation and the start of the scan sequence)
2. Choice of spiral parameters to maximize the contrast in the target vessel (i.e., *scan duration*, collimation, and *table speed*)
3. Reconstruction of two-dimensional image data into 3D image data



**Fig. 33-23** A four-detector array with a beam pitch of 2.0 covers eight times the tissue volume of a single-slice spiral CT.

CTA has several advantages over conventional angiography. CTA uses spiral technology; therefore an arbitrary image within the volume of data can be retrospectively reconstructed without exposing the patient to additional IV contrast medium or radiation. Furthermore, during postprocessing of the image data, overlying structures can be eliminated so that only the vascular anatomy is reconstructed. Finally, because CTA is an IV procedure that does not require arterial puncture, only minimal postprocedure observation is necessary.

Currently CTA is not designed to replace angiography as a diagnostic mode; rather, it is a complementary examination that allows image reconstructions of different body planes without further radiation to the patient. Fig. 33-24 demonstrates the vessels of the brain, whereas Fig. 33-25 highlights the renal vessels in a 3D format.

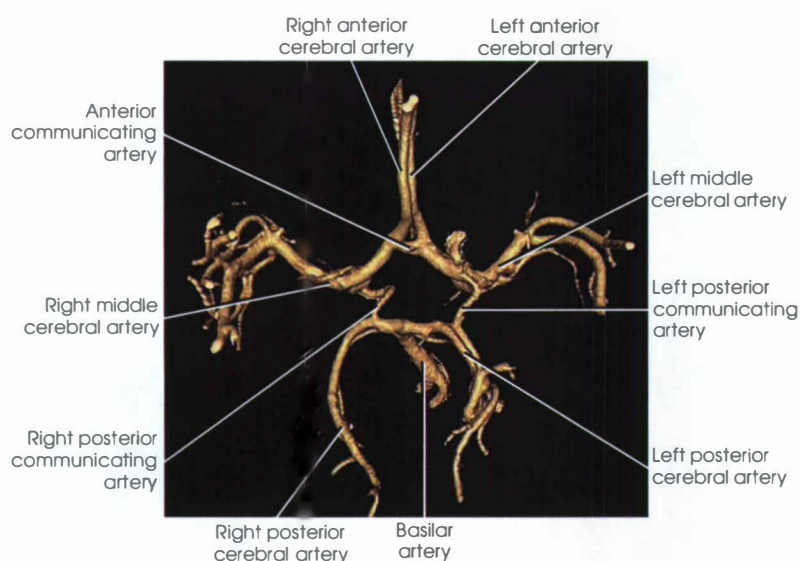


Fig. 33-24 Color CT angiography of the circle of Willis.

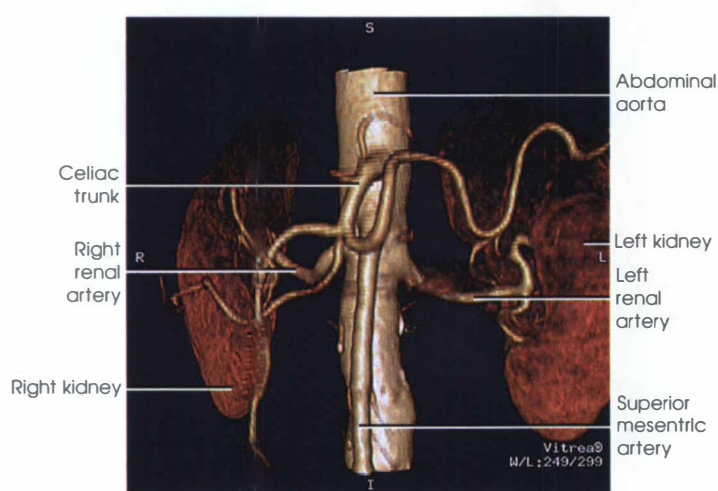


Fig. 33-25 Color CT angiography of the renal vessels in 3D format.



### THREE-DIMENSIONAL IMAGING

A rapidly expanding area of CT is three dimensional (3D) imaging. This is a *post-processing* technique that is applied to the raw data to create realistic images of the surface anatomy to be visualized.

The introduction of advanced computers and faster software programs has dramatically increased the applications of 3D imaging. The common techniques used in creating three-dimensional images include: *maximum intensity projection (MIP)*, *shaded surface display (SSD)*, and *volume rendering (VR)*. All techniques use three initial steps to create the 3D images from the original CT data.

1. Construction of a volume of 3D data from the original two-dimensional CT image data. This same process is used in MPR.
2. *Segmentation* to crop or edit the target objects from the reconstructed data. This step eliminates unwanted information from the CT data.
3. *Rendering* or *shading* to provide depth perception to the final image.

### Maximum intensity projection

The MIP technique consists of reconstructing the brightest pixels from a stack of two- or three-dimensional image data into a three-dimensional image. The data are rotated on an arbitrary axis, and an imaginary ray is passed through the data in specific increments. The brightest pixel found along each ray is then *mapped* into a gray-scale image. The MIP technique is commonly used for CTA.

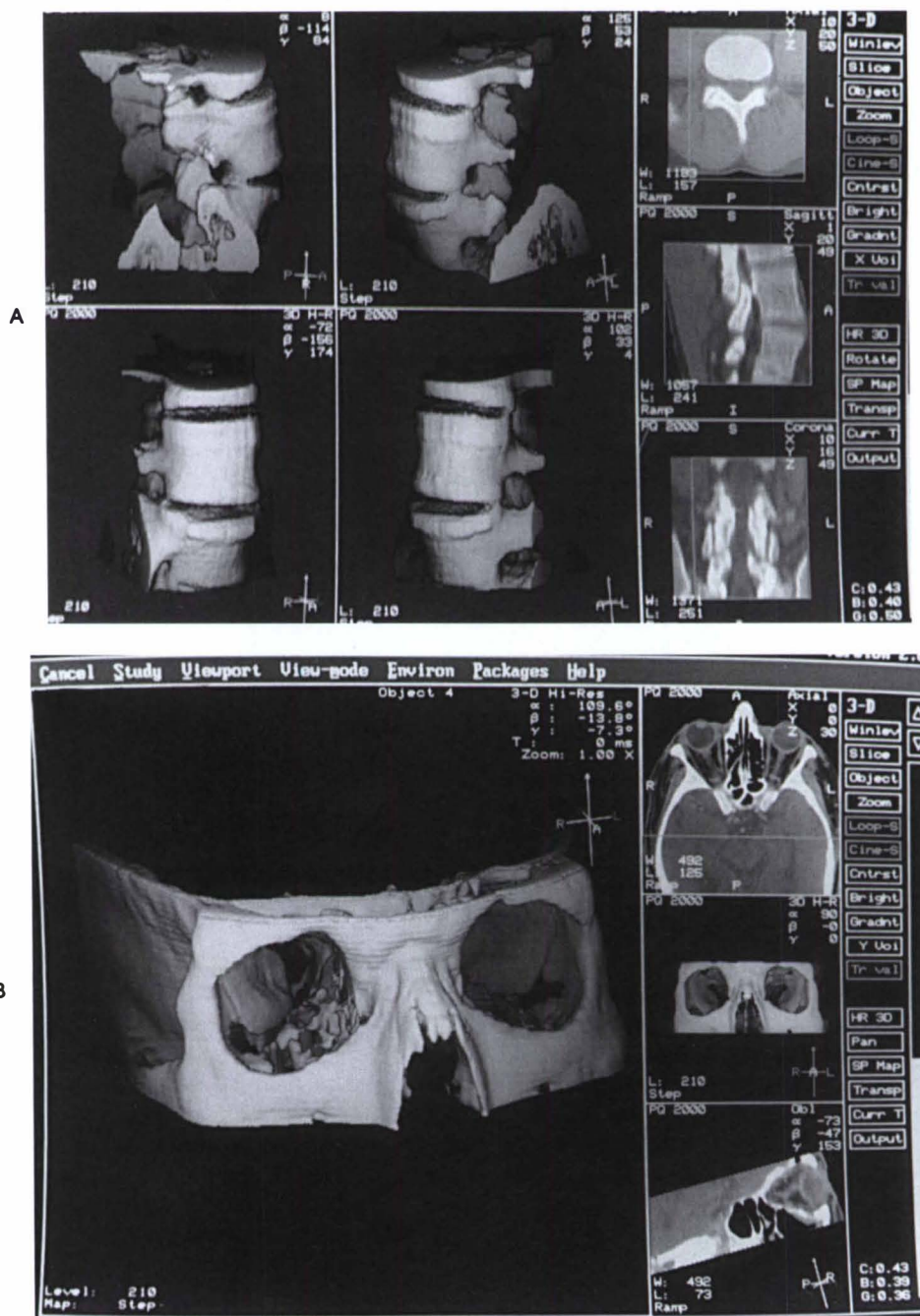


Fig. 33-26 Three-dimensional images. **A**, Lumbar spine. **B**, Bony orbits.

(Courtesy Marconi Medical Systems, Inc., Highland Heights, OH.)

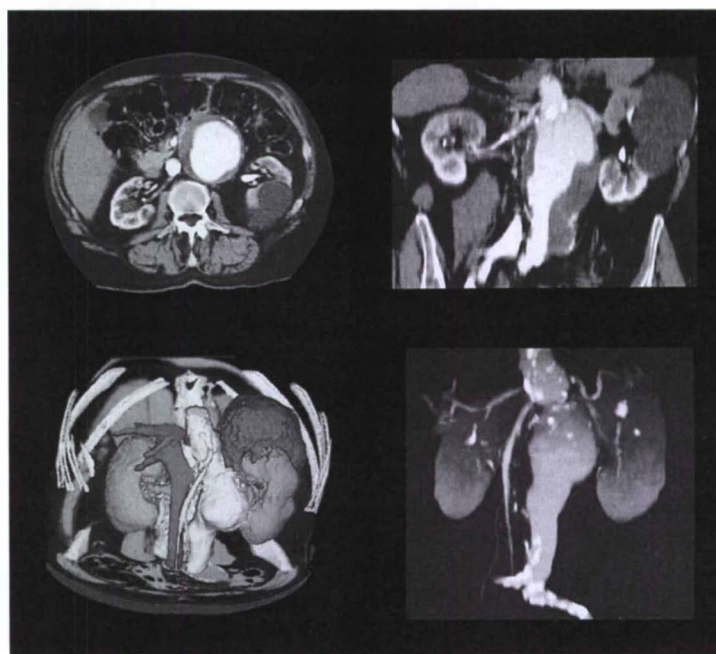
### Shaded surface display

An SSD image provides a three-dimensional image of a particular structure's surface. Once the original two-dimensional data are reconstructed into three-dimensional information, the different tissue types within the image need to be separated. This process, called *segmentation*, can be performed by drawing a line around the tissue of interest or more commonly by setting *threshold values*. A threshold value can be set for a particular CT number; the result is that any pixel having an equal or higher CT number than the threshold value will be selected for the three-dimensional image. Once the threshold value is set and the data are reconstructed into a three-dimensional image, a shading technique is applied. The shading or rendering technique provides depth perception in the reconstructed image.

### Volume rendering

Volume rendering techniques incorporate the entire volume of data into a 3D image by summing the contributions of each voxel along a line from the viewer's eye through the data set. This results in a 3D image in which the dynamic range throughout the image is preserved. Rather than being limited to surface data, a VR image can display a wide range of tissues that will accurately depict the anatomic relationships between vasculature and viscera. Since VR incorporates and processes the entire data set, much more powerful computers are required to reconstruct 3D VR images at a reasonable speed.

Referring physicians and surgeons use three-dimensional images to clinically correlate CT images to the actual anatomic contours of their patients (Fig. 33-26). These reconstructions are especially useful in surgical procedures. Three-dimensional reconstructions are often requested as part of patient evaluation after trauma and for presurgical planning. Fig. 33-27 provides examples of the three common 3D rendering techniques.



**Fig. 33-27** Common 3D rendering techniques used in CT.

(Courtesy Elscint, Hackensack, N.J.)



## RADIATION TREATMENT PLANNING

Radiation therapy has been used for nearly as long as radiology has been in existence. The introduction of CT has had a major impact on radiation treatment planning. The use of spiral CT in conjunction with MPR provides a three-dimensional approach to radiation treatment planning. This method helps the dosimetrist to plan treatment so that the radiation dose to the target is maximized and the dose to normal tissue is minimized. New 3D simulation software offers the following: volumetric, high-precision localization; calculation of the geometric center of the defined target; patient marking systems; and virtual simulators capable of producing digitally reconstructed radiographs in *real time*. With the new, specially designed software, a single CT simulation procedure can replace a total of three procedures (one conventional CT and two conventional simulations) for radiation treatment planning.

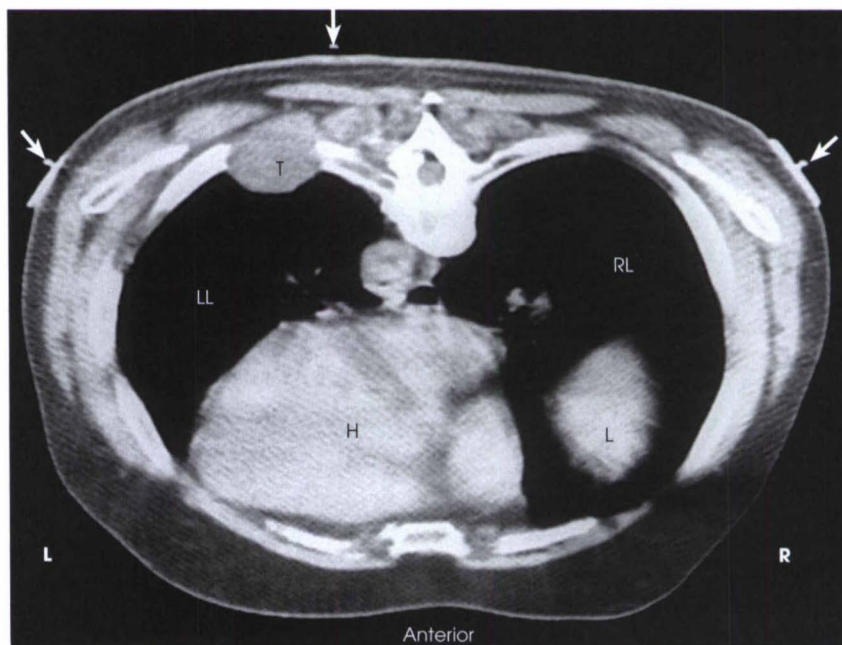
If the CT system is being used for radiation treatment planning, the standard curved couch should not be used. Instead, a flat board should be placed on the couch. In this way the actual therapy delivery can be simulated more accurately. Fig. 33-28 demonstrates the external skin markers and structures that will be in the beam's path.

## QUALITY CONTROL

The goal of any quality assurance program in CT is to ensure that the system is producing the best possible image quality with the minimum radiation dose to the patient. A CT system is a complex combination of sensitive and expensive equipment that requires systematic monitoring for performance and image quality. Most CT systems require weekly or biweekly preventative maintenance to ensure proper operation.

Preventative maintenance is usually performed by a service engineer from the manufacturer or a private company. Increasingly, however, the technologist is being assigned the responsibility of performing and documenting routine quality assurance tests. Many technologists routinely perform daily test scans on a water phantom to measure the consistency of the CT numbers and to record the standard deviation. As data are recorded over time, the CT scanner's current operating condition, as well as its performance over longer time periods, can be evaluated. Many units are also capable of *air calibrations*, which do not require the water phantom and can be performed between patients for unit self-calibration.

A CT phantom is typically multisectioned and is constructed from plastic cylinders, with each section filled with test objects designed to measure the performance of specific parameters. Some phantoms are designed to allow numerous parameters to be evaluated with a single scan. The recommended quality assurance tests for evaluating routine performance include the following: contrast scale and mean CT number of water, high-contrast resolution, low-contrast resolution, laser light accuracy, noise and uniformity, slice thickness, and patient dose.



**Fig. 33-28** Patient in prone position for radiation treatment planning. Radiopaque markers (arrows) demonstrate location of treatment field skin marks: tumor (T), heart (H), liver (L), right lung (RL), and left lung (LL).



## Comparison of Computed Tomography and Magnetic Resonance Imaging

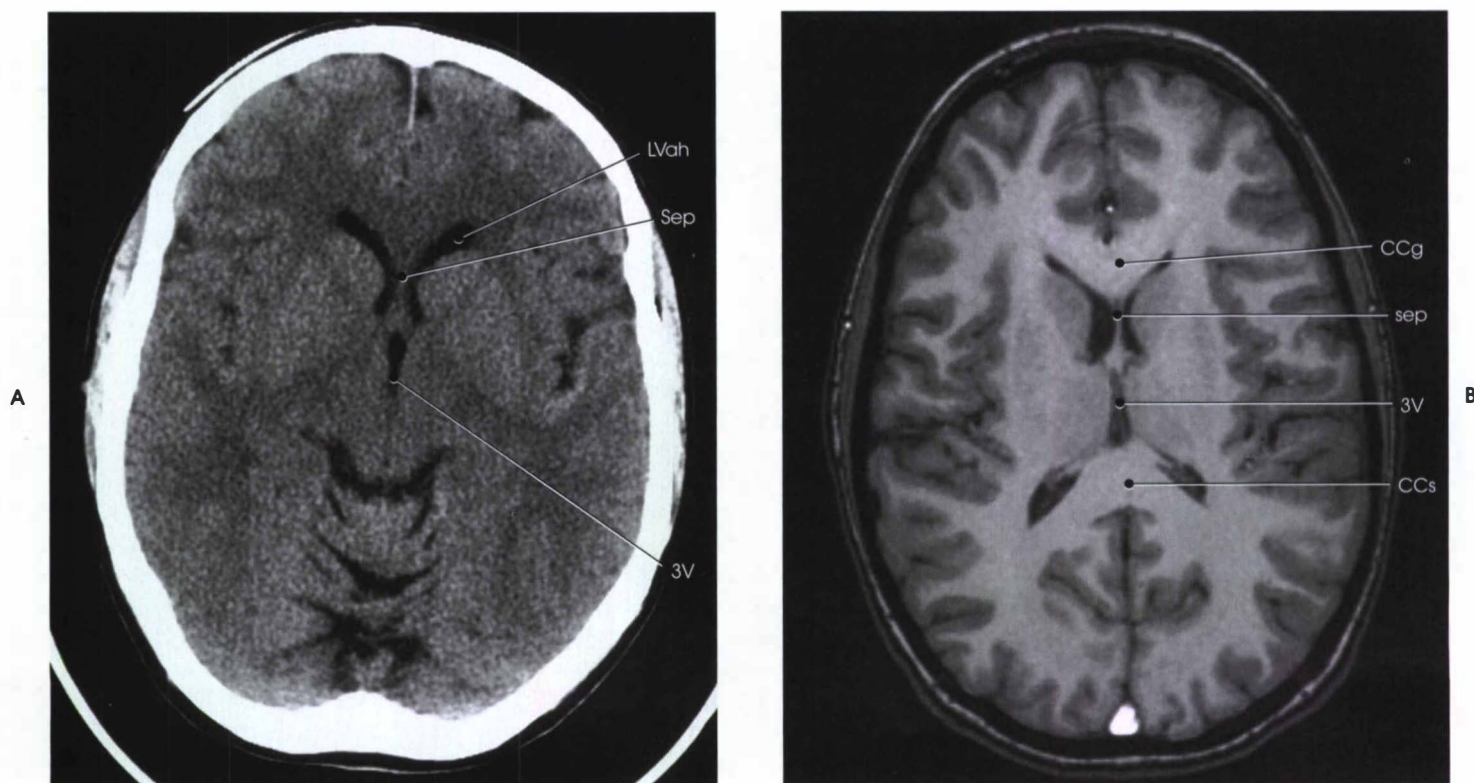
As CT was developing and advancing into a significant diagnostic modality, magnetic resonance imaging (MRI) was also progressing. Like CT, MRI was first used to image the brain; whole-body scans were developed shortly afterward. As MRI advanced and the quality of the images improved, it became apparent that MRI images exhibited better low-contrast resolution than CT images. Brain soft tissue detail is not demonstrated as well with CT as with MRI performed at approximately the same level (Fig. 33-29).

The initial introduction of MRI raised concerns that CT scanners would become obsolete. However, each modality has been found to have unique capabilities. Thus CT and MRI are useful for different clinical applications. As previously mentioned, CT does not demonstrate soft tissue as well as MRI; however, CT demonstrates bony structures better than MRI.

Patients often have ferrous metal within their bodies. Such patients cannot always be scanned by MRI. CT is one option for these patients. The CT scanner does not affect metal in a patient, but metal can cause artifacts on CT images when the metal lies within the scan plane.

Many patients (especially pediatric and trauma patients) are extremely claustrophobic, combative, or uncooperative. CT is useful for scanning these patients quickly and easily, because of the small gantry, relatively large aperture, and short scan times.

Because equipment costs are lower and a greater number of procedures can be accomplished per day, CT can often be a less costly examination than MRI. Physicians have found that CT and MRI can be complementary examinations. In many situations, both examinations are ordered to provide as much diagnostic information as possible.



**Fig. 33-29** A, Axial CT scan of lateral ventricles (LVah). B, Axial MR scan of corpus callosum.

(From Kelly LL, Peterson CM: *Sectional anatomy for imaging professionals*, St Louis, 1997, Mosby.)

## The Future

In the last 5 years, CT has significantly increased its diagnostic capabilities. The development of spiral CT was central to the advancement of CT as a discipline. With the rapid advancements in technology, the CT technologist has an increased responsibility to understand contrast dynamics and the new spiral scan parameters of pitch, collimation, scan timing, and table speed.

Advances in computing power and design have provided workstations that can generate three-dimensional models in 30 seconds or less, rotate the models along any axis, and display the models with varying parameters. Digital subtraction CT, multimodality image superimposition, and translucent shading of soft tissue structures are some of the new applications coming from technologic advancements. In the near future, CT will provide image data sets that will allow physicians to manipulate the anatomy on virtual reality and other graphics platforms. As the higher quality images increase the accuracy of diagnosis and treatment, patient care will be improved. Because of CT's superb diagnostic information and cost-effectiveness, this imaging modality will continue to be a highly respected diagnostic tool.

## Definition of Terms

**air calibration** Scan of air in gantry; based on a known value of  $-1000$  for air, the scanner will calibrate itself according to this density value relative to the actual density value measured.

**algorithm** Mathematic formula designed for computers to carry out complex calculations required for image reconstruction; designed for enhancement of soft tissue, bone, and edge resolution.

**aperture** Opening of the gantry through which patient passes during scan.

**archiving** Storage of CT images on long-term storage device such as cassette tape, magnetic tape, or optical disk.

**artifact** Distortion or error in image that is unrelated to subject being studied.

**attenuation coefficient** CT number assigned to measured remnant radiation intensity after attenuation by tissue density.

**axial** Describes plane of image as presented by CT scan; same as *transverse*.

**bolus** Preset amount of radiopaque contrast medium injected rapidly per IV administration to visualize high-flow vascular structures, usually in conjunction with dynamic scan; most often injected using a pressure injector.

**cathode ray tube (CRT)** Electronic monitor used for image display or scan protocol display; resolution of a CRT depends on lines per inch; the greater the lines per inch, the better the resolution.

**computed tomography (CT)** Process by which computer-reconstructed transverse (or axial) image of a patient is created by an x-ray tube and detector assembly rotating 360 degrees about a specified area of the body; also called CAT (*computed axial tomography*) scan.

**CT angiography** Use of volumetric CT scanning with spiral technique to acquire image data that are reconstructed into three-dimensional CT angiograms.

**CT number** Arbitrary number assigned by computer to indicate relative density of a given tissue; CT number varies proportionately with tissue density; high CT numbers indicate dense tissue, and low CT numbers indicate less dense tissue. All CT numbers are based on the density of water, which is assigned a CT number of 0; also referred to as a *Hounsfield unit*.

**contrast resolution** Ability of a CT scanner to demonstrate different tissue densities.

**data acquisition system (DAS)** Part of detector assembly that converts analog signals to digital signals that can be used by the CT computer.

**detector** Electronic component used for radiation detection; made of either high-density photoreactive crystals or pressurized stable gases.

**detector assembly** Electronic component of CT scanner that measures remnant radiation exiting the patient, converting the radiation to an analog signal proportionate to the radiation intensity measured.

**direct coronal** Describes the position used to obtain images in coronal plane; used for head scans to provide images at right angles to axial images; patient is positioned prone for direct coronal images and supine for reverse coronal images.

**dynamic scanning** Process by which raw data are obtained by continuous scanning; images are not reconstructed but are saved for later reconstruction; most often used for visualization of high-flow vascular structures; can be used to scan a non-cooperative patient rapidly.

**field of view (FOV)** Area of anatomy displayed by the CRT; can be adjusted to include entire body section or a specific part of the patient anatomy being scanned.

**gantry** Part of CT scanner that houses x-ray tube, cooling system, detector assembly, and DAS; often referred to as the "doughnut" by patients.

**generation** Description of significant levels of technologic development of CT scanners; specifically related to tube/detector movement.

**gray-scale image** Analog image whereby each pixel in the image corresponds to a particular shade of gray.

**helical CT** Relatively new data acquisition method that combines continuous gantry rotation with continuous table movement to form a helical path of scan data; also called *spiral CT*.

**high-resolution scans** Use of scanning parameters that enhance contrast resolution of an image, such as thin slices, high matrices, high-spatial frequency algorithms, and small-display FOV.



**host computer** Primary link between system operator and other components of imaging system.

**Hounsfield unit (HU)** Number used to describe average density of tissue; term is used interchangeably with *CT number*; named in honor of Sir Godfrey Hounsfield, the man generally given credit for development of the first clinically viable CT scanner.

**image misregistration** Image distortion caused by combination of table indexing and respiration; table moves in specified increments, but patient movement during respiration may cause anatomy to be scanned more than once or not at all.

**index** Table movement; also referred to as *table increments*.

**mapping** Assignment of appropriate gray level to each pixel in an image.

**matrix** Mathematical formula for calculation made up of individual cells for number assignment; CT matrix stores a CT number relative to the tissue density at that location; each cell or "address" stores one CT number for image reconstruction.

**maximum intensity projection (MIP)** Reconstruction of brightest pixels from stack of image data into a three-dimensional image.

**multiplanar reconstruction (MPR)**

Postprocessing technique applied to stacks of axial image data that can then be reconstructed into other orientations or imaging planes.

**noise** Random variation of CT numbers about some mean value within a uniform object; noise produces a grainy appearance in the image.

**partial volume averaging** Calculated linear attenuation coefficient for a pixel that is a weighted average of all densities in the pixel; the assigned CT number and ultimately the pixel appearance are affected by the average of the different densities measured within that pixel.

**pixel (picture element)** One individual cell surface within an image matrix used for CRT image display.

**postprocessing techniques** Specialized reconstruction techniques that are applied to CT images to display the anatomic structures from different perspectives.

**primary data** CT number assigned to the matrix by the computer; the information required to reconstruct an image.

**protocol** Instructions for CT examination specifying slice thickness, table increments, contrast administration, scan diameter, and any other requirements specified by the radiologist.

**quantum noise** Any noise in the image that is a result of random variation in the number of x-ray photons detected.

**real time** Ability to process or reconstruct incoming data in a matter of milliseconds.

**reconstruction** Process of creating a digital image from raw data.

**region of interest (ROI)** Measurement of CT numbers within a specified area for evaluation of average tissue density.

**rendering** Process of changing the shading of a three-dimensional image; commonly used to increase depth perception of an image.

**retrieval** Reconstruction of images stored on long-term device; can be done for extra film copies or when films are lost.

**scan** Actual rotation of x-ray tube about the patient; used as a generic reference to one slice or an entire examination.

**scan diameter** Also referred to as the *zoom* or *focal plane* of a CT scan; predetermined by the radiographer to include the anatomic area of interest; determines FOV.

**scan duration** Amount of time used to scan an entire volume during a single spiral scan.

**scan time** X-ray exposure time in seconds.

**segmentation** Method of cropping or editing target objects from image data.

**shaded surface display (SSD)** Process used to generate three-dimensional images that show the surface of a three-dimensional object.

**shading** Postprocessing technique used in three-dimensional reconstructions to separate tissues of interest by applying a threshold value to isolate the structure of interest.

**slice** One scan through a selected body part; also referred to as a *cut*; slice thickness can vary from 1 mm to 1 cm, depending on the examination.

**slip ring** Low-voltage electrical contacts within the gantry designed to allow continuous rotation of an x-ray tube without the use of cables connecting internal and external components.

**spatial resolution** Ability of a CT scanner to demonstrate small objects within the body plane being scanned.

**spiral CT** Relatively new data acquisition method that combines a continuous gantry rotation with a continuous table movement to form a spiral path of scan data; also called *helical CT*.

**streak artifact** Artifact created by high-density objects that result in an arc of straight lines projecting across the FOV from a common point.

**system noise** Inherent property of a CT scanner; the difference between the measured CT number of a given tissue and the known value for that tissue; most often evaluated through the use of water phantom scans.

**table increments** Specific amount of table travel between scans; can be varied to move at any specified increment; most protocols specify from 1 mm to 20 cm, depending on type of examination; also referred to as *indexing*.

**table speed** Longitudinal distance traveled by the table during one revolution of the x-ray tube.

**threshold value** CT number used in defining the corresponding anatomy that will comprise a three-dimensional object; any pixels within a three-dimensional volume having the threshold value (CT number) or higher will be selected for the three-dimensional model.

**useful patient dose** Radiation dose received by the patient that is actually detected and converted into an image.

**voxel (volume element)** Individual pixel with the associated volume of tissue based on the slice thickness.

**window** Arbitrary numbers used for image display based on various shades of gray; window width controls the overall gray level and affects image contrast; window level (center) controls subtle gray images within a certain width range and ultimately affects the brightness and overall density of an image.



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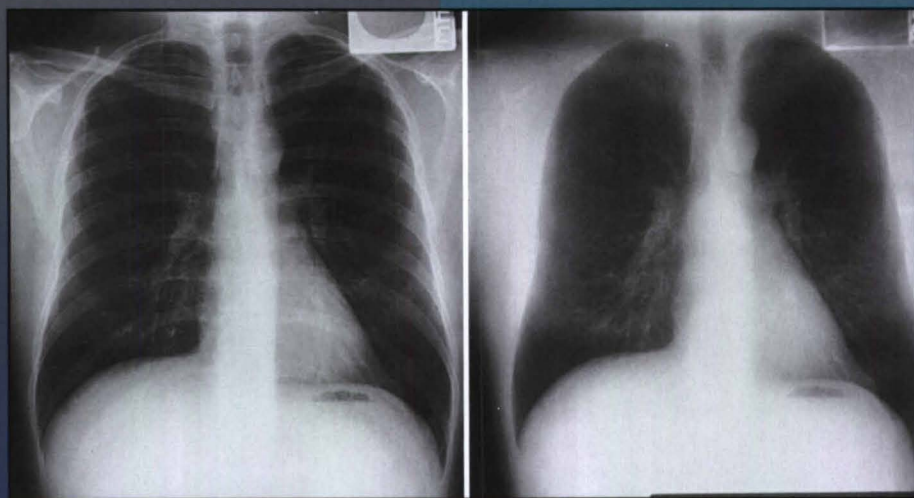


34

# COMPUTED RADIOGRAPHY

REX E. PROFIT

Standard computed radiographic chest image (*left*) and soft tissue image (*right*) of only lung tissue using the energy subtraction process.



## OUTLINE

The computer, 356  
Principles of computed radiography, 356  
Historical development, 357  
Operational components:  
    separation of functions, 357  
Characteristics of a computed radiographic image, 361  
Clinical applications, 362  
Other techniques to improve diagnostic efficacy, 365  
Clinical acceptance, 366  
Quality assurance concerns, 366  
Pitfalls, 366  
Benefits, 367  
Conclusion, 369  
Definition of terms, 370

## THE COMPUTER

Following the introduction of the computer in medicine, the practice and development of radiologic procedures expanded rapidly. Specifically for computed radiography, without the computer, the specialty would not have been possible. Understanding computed radiography requires basic knowledge of computer terminology and basic operation skills on computer systems. All computer systems can be a challenge if technologists are unfamiliar with the terminology or are a little reluctant to use computers. For more information about computer fundamentals, please refer to Volume 3 of the sixth through ninth editions of this Atlas. Additional information can also be found in several recently published books listed in the selected bibliography at the end of this chapter.

Various methods for enhancing the diagnostic capability of x-ray images have been used over the years. In stereoscopic radiography, for example, two images of the same anatomic structure are obtained, with the x-ray tube shifted six degrees for the second image. The two x-ray images are then placed side-by-side on an illuminator and viewed using a stereoscope. This three-dimensional viewing helps the radiologist to some degree, but the process is operationally cumbersome. An old stereoscopic viewer appears on Chapter cover page.

## PRINCIPLES OF COMPUTED RADIOGRAPHY

Since the days of Wilhelm Conrad Roentgen, radiography has been continuously improved and diversified. Throughout the 1990s and into the new century, the fluorescent x-ray film-screen combination remains the most widely used radiographic method. However, conventional film-screen radiography limits image manipulation to "hot-lighting" or duplication. Modalities such as computed tomography (CT), ultrasonography, and magnetic resonance imaging (MRI), are *digital*\*; they provide cross-sectional images and allow the image to be manipulated. Conventional projection radiography, which accounts for nearly 70% of a radiology department's volume, remained an *analog* modality until the past decade.

## ANALOG AND DIGITAL INFORMATION

Analog information is represented in a continuous fashion, whereas digital information is represented in discrete units. An analogy is the difference between oil paints and a box of crayons. The oil paints can be mixed to provide an infinite number of color shades, whereas the box of crayons can provide only the number of colors in the box. The advantage of digital information is that the location and nature of each digital level are known and can be adjusted accordingly. In all digital imaging systems, including CT, MRI, ultrasonography, and computed radiography, information is acquired by a process called *analog-to-digital conversion*. After the x-ray or ultrasound beam has passed through the patient, or is reflected back within the patient for ultrasound, it is still an analog signal. This signal varies smoothly from zero (all the radiation has been absorbed by some part of the patient) to maximum intensity (no radiation has been absorbed).

In a CT scanner the analog-to-digital conversion occurs when the x-ray beam strikes the detector located in the gantry (see Chapter 33). Each detector corresponds to an anatomic location that absorbed the radiation, and the detectors have a limited number of responses. The number of responses the detectors can make is called the *gray-level display* of the system. If the system has 256 gray levels (0 being black, 256 being white), the computer assigns the gray level of these 256 shades that is closest to the intensity of the radiation striking the detector. The system then reproduces the image by combining the responses of all the detectors.

In a computed radiographic system, the analog-to-digital conversion occurs when the exposed image plate is scanned with a laser. At this point the image reader, as explained later in this chapter, converts the emitted light pattern to digital information.

## COMPUTED AND ANALOG RADIOGRAPHY

*Computed radiography* (often abbreviated CR) refers to conventional projection radiography in which the image is acquired in digital format using an imaging plate rather than film. Conventional projection radiography includes all of the radiographic procedures that are now performed using a film-screen system. These procedures include the familiar procedures that comprise the majority of radiographic examinations performed in an imaging facility: chest, abdomen, and orthopedic radiographs as well as contrast-enhanced radiographic studies such as excretory urography and barium studies of the gastrointestinal tract.

The major obstacle to developmental changes in the field of conventional projection radiography has been that one specific medium—x-ray film—serves three distinct functions in the radiographic process: (1) x-ray film is the "sensor" to acquire the diagnostic information; (2) it is used to display the information; and (3) it is used to store the information.

\*Almost all italicized words on the succeeding pages are defined at the end of this chapter.



## Historical Development

At the 1981 International Congress of Radiology meeting in Brussels, Fuji Photo Film Co., Ltd., introduced the concept of computed radiography employing *photostimulable phosphor* plate technology. In 1983 computed radiography was first used clinically in Japan, and by 2003 more than 25,000 systems will be in clinical use worldwide.

Computed radiography using the phosphor plate provides excellent image quality. Computed radiographic technology is digital and supports the development of a variety of computer-based diagnostic information-processing systems. As such, computed radiography provides a missing link for the completely electronic radiographic imaging department and is now a practical imaging modality.

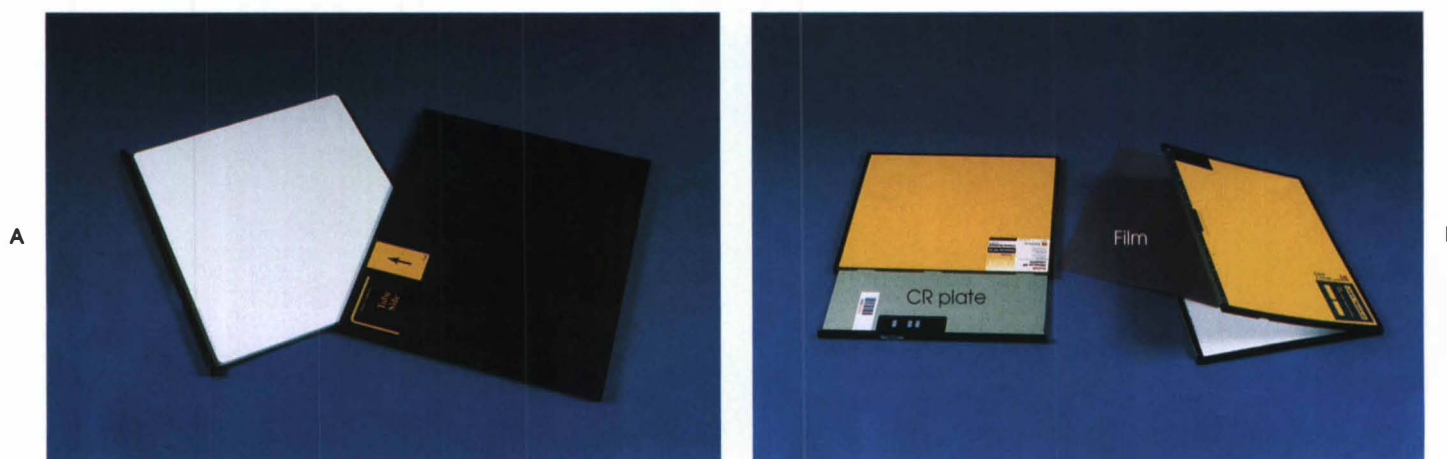
Converting conventional projection radiography into a digital format can be accomplished (1) by digitizing the standard radiographic film images or (2) by acquiring a digital image directly by having the x-rays strike an electronic sensor or an image intensifier or by using an imaging plate that is then scanned with a laser and the emitted light read by an electronic sensor. The second technique is currently the best option for computed radiography when a reusable imaging plate is used. In the remainder of this chapter, computed radiography refers to imaging performed using imaging plates.

Unlike scanned projection radiography or intensifier-based systems, which require that images be acquired on dedicated equipment, the reusable photostimulable phosphor plate system can be used with standard radiographic imaging equipment. The key to computed radiography's development is separation of the functions of sensing, displaying, and storing information. Each function uses separate media and devices, and each function can be separately manipulated; however, central control of the final image is maintained through computer technology.

## Operational Components: Separation of Functions

### IMAGE ACQUISITION FUNCTIONS

The image acquisition or "sensor" function is served by the photostimulable phosphor *imaging plate*, which, like x-ray film, receives the portion of the x-ray beam that has passed through the patient. This imaging plate looks much like an intensifying screen (Fig. 34-1, A) and is placed in a cassette similar in external appearance to an x-ray film cassette (Fig. 34-1, B). The cassette consists of a frame of either lightweight aluminum or rigid steel, with the x-ray tube side composed of honeycombed carbon fiber to produce a low x-ray attenuation surface. The back of the cassette is lined with a thin layer of lead to absorb backscatter radiation. The primary function of the cassette is to protect the imaging plate, not to control light.



**Fig. 34-1** A, Tube side of computed radiography cassette with imaging plate partially inserted. B, Back side of the CR cassette (left) and older film-screen cassette (right).

The imaging plate contains a layer of europium-doped barium fluorohalide ( $\text{BaF}_x\text{:Eu}^{2+}$ ) crystals (the photostimulable phosphor). The most common commercial products, using these barium fluorohalide crystals, are based on either  $\text{BaFBr:Eu}^{2+}$ ,  $\text{BaF(BrI):Eu}^{2+}$ , or  $\text{BaSrFBr:Eu}^{2+}$ . When x-rays strike the photostimulable phosphor crystals, the  $\text{BaF}_x\text{:Eu}^{2+}$  is changed to a new semi stable state. The distribution of these semi stable molecules forms the *latent image*. The photostimulable phosphor layer is applied to polyester base and the coated with a clear protective layer composed of fluorinated polymer material (Fig. 34-2).

A supporting layer protects the phosphor layer from external shocks. The supporting layer also prevents reflection of the laser light. Next is a backing layer that protects the imaging plate from scratches during transfer and storage. Last is a bar code label that contains a number assigned to the imaging plate. This bar code provides a mechanism for associating each imaging plate with patient identification and related examination and positioning information.

The imaging plate is flexible and less than 1 mm thick. A unique property of the phosphor material is its “memory” capability: it can maintain a latent image for a certain period of time after exposure to x-rays. Although some image degradation occurs as time elapses, the plate retains a diagnostic image for at least 24 hours.

A valuable characteristic of the imaging plate is its extreme *dynamic range*. The imaging plate demonstrates an excellent linear response to the intensity of x-ray exposure over a broad range. When the imaging plate response is compared with the characteristic H&D curve of radiographic film (Fig. 34-3), the imaging plate shows superior performance capability in that it provides far more information in the low- and high-exposure regions of the image.

The *image plate reader* is another important component of the image acquisition control in computed radiography (Fig. 34-4). The image reader converts the continuous analog information (latent image) on the imaging plate to a digital format. As the laser in the image reader scans the imaging plate, the portion of the plate struck by a laser emits light. High-efficiency light guides to photomultiplier tubes direct this emitted light where it is converted to digital electric signals.

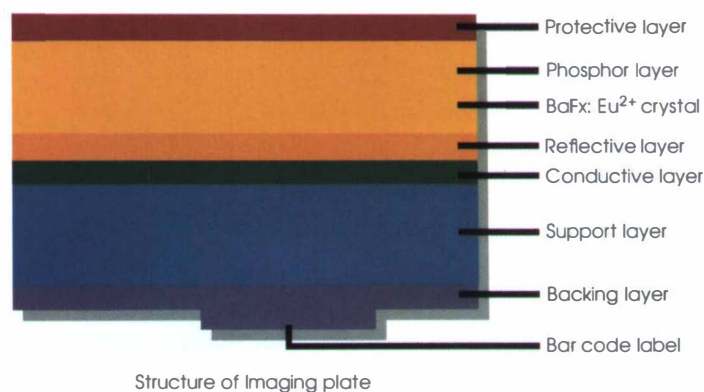


Fig. 34-2 Schematic diagram showing layered composition of photostimulable imaging plate.

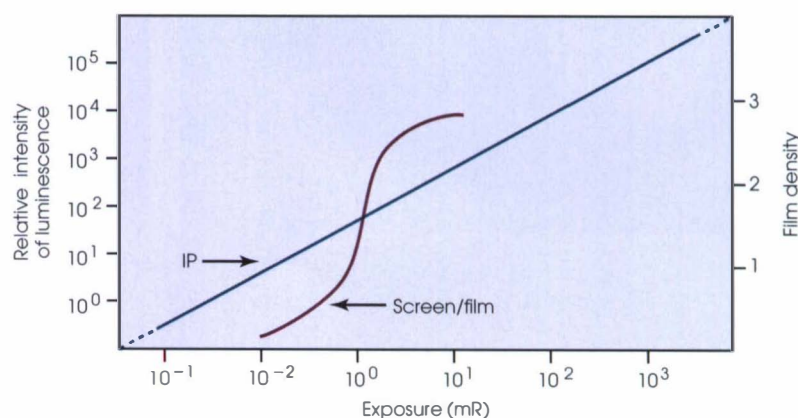


Fig. 34-3 Comparison of radiographic film H&D response curve to linear plate response.



The first reader systems became available in 1983 and were capable of processing only 40 plates per hour. Reader systems today are more compact and are capable of processing approximately 110 to 140 plates per hour. Several image readers can be interfaced to each other or to laser printers, computer workstations, or digital archives. For high-volume applications such as chest radiography, stand-alone systems with integrated image processors are available. In any of the reader systems the imaging plate is transported internally through all the various stages of processing.

### DISPLAY FUNCTIONS

The display of computed radiography data is basically the result of *spatial frequency response* and *gradation processing*. Spatial frequency response controls the contrast (sharpness) of the boundaries between two structures of different densities. Gradation processing controls the range of densities used to display structures on the image; it is similar to the window settings used in CT for display. The two different characteristics—contrast and density—are optimized by the digital image processor for the specific anatomic region being studied.

To produce an image for viewing, the computed radiography computer system constructs (formats) the image from the raw data set as read from the photostimulable plate. Because the computed radiographic image is in a digital format, the primary image data can be manipulated to accentuate or suppress various features of the image. Consequently the image can be tailored to a specific clinical task. This is similar to the operation of other digital imaging modalities such as CT, in which the window and level setting of the image can be changed to visualize a specific structure such as the liver or lung.

If the user specifies no special parameters, the image is reconstructed using the *default* (preset) settings that the specific medical facility has decided produce the images of the best quality. If special image characteristics are desired to highlight specific structures, the radiographer or other user can change the reconstruction factors. The final image can be displayed on a monitor or produced as a hard-copy image on film or another medium. Unlike the CT scan, the computed radiographic image is reconstructed each time from the primary data. If the image is displayed on a monitor, the user to examine all features of the image to best advantage can adjust the image characteristics visually. Various workstations with high-resolution *cathode ray tube (CRT)* monitors can be directly interfaced to the computed radiography unit to assist in the display process.



**Fig. 34-4** Example of two computed radiography readers. **A**, A high volume reader capable of processing between 110 and 140 imaging plates per hour. **B**, A much smaller system designed for medical offices, surgery, or ICU units, capable of processing 50 to 60 imaging plates per hour.

(**B**, Courtesy of FujiFilm Medical Systems, USA.)



The electronic workstation undoubtedly represents the alternator (illuminator [view box]) of the future. Workstations may be linked to a central image archive (an "electronic file room") and also to the text data from the radiology and hospital information systems to provide a central clearing area for all information (images and text) needed by the technologist or radiologist. The functions for these workstations, which continue to be expanded (Box 34-1), allow the user to alter the image display to best advantage for interpretation. The gradational enhancement (contrast and density) and spatial frequency (sharpness) enhancement can be varied on the workstation; this is similar to formatting the hard-copy image. If, for example, two images have been taken sequentially or using different energy characteristics (see the discussion of dual-energy subtraction), the images can be subtracted much as in angiography with the use of radiographic film and digital subtraction systems. The image also can be magnified, rotated, flipped, or inverted. Statistical analyses can be performed on portions of the image by calculating surface areas and estimated volumes or by characterizing the change in density in a part of the image. Most important for daily operations, however, is the fact that the workstation contains a database that enables the user to easily locate images and create lists of images for conferences, interpretation, and teaching files.

The number of CRT monitors required for an interpretation workstation is still under review. However, it is clear that a minimum of two monitors is needed. The monitor resolution factor remains a point of contention among experts in this field. Currently,  $1K \times 1K$  *matrix* monitors are generally used. The resolution is adequate for most studies, and the cost is within reason. However,  $2K \times 2K$  monitors are the norm for primary radiologist review workstations. With  $2K \times 2K$  resolution, all studies can be appropriately displayed with little or no loss of diagnostic information. Finally, the use of  $4K \times 4K$  monitors is under discussion. These monitors require that the image acquisition be of  $4K \times 4K$  architecture. If the data are acquired in a  $4K \times 4K$  data set, they can be fully displayed on  $4K \times 4K$  monitors. Cost remains a major consideration in the use of these very costly high-resolution monitors, as well as the speed factor in handling such large data packets of information and the data storage.

Computed radiography also offers several options for film-based display. Fig. 34-5 shows a 2-on-1 format of an identical shoulder image. The image on the left demonstrates the shoulder with display factors similar to those of a conventional film-screen radiograph. An *edge-enhanced* image is also automatically displayed, as seen in the right image. Certain studies and the imaging of some pathologic conditions benefit from this enhanced image.

## STORAGE FUNCTIONS

Computed radiography decreases image archive storage space requirements by reducing the size of films stored or by converting bulky film storage to electronic storage. Benefits include tremendous space savings, reduction in image retrieval time, and decreased film loss.

Several points about the design of electronic image archive devices must be considered. Flexibility is important. The device should interface with desired modalities and should be expandable. The amount of storage on the electronic image archive should be adequate for the amount of data to be stored. The storage capacity of an electronic image archive depends on several variables, including the size of the basic storage unit (i.e., magnetic tape, Digital Video Disc [DVD] or optical disk), the number of units on-line, and the ratio of data compression that is used.

### BOX 34-1

#### Workstation functions

- Gradation enhancement
- Spatial frequency enhancements
- Statistical analysis
- Rotation/inversion
- Anatomic measurements
- Short-term database functions
- Dynamic range control
- Magnification

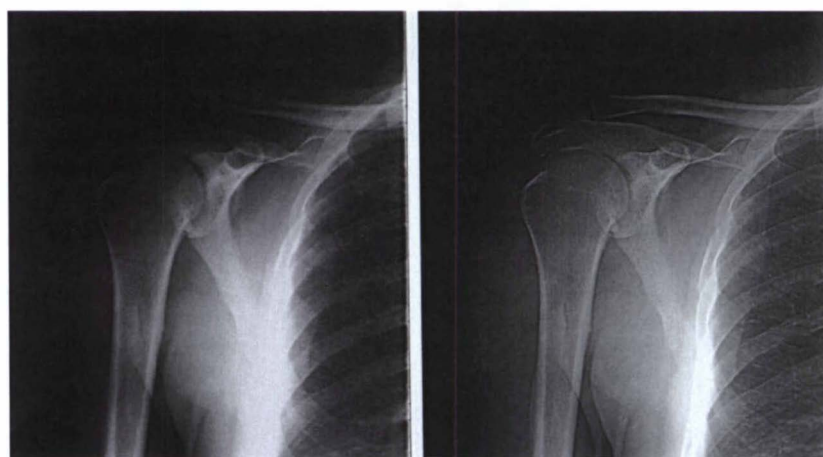


Fig. 34-5 CR image of a shoulder with conventional (*left*) and edge-enhanced (*right*) display parameters.

Magnetic tape, DVD, and optical disk are currently the storage media of choice for computed radiographic images. These images contain more total data per individual image than the images of other digital modalities, including CT and ultrasonography (Table 34-1). Each computed radiographic image contains about 8 megabytes (MB) of data. For example, a PA or lateral chest image contains about 16 MB of data; that amount of data requires the same electronic storage as the first four volumes of digital text from the *Encyclopedia Britannica*. One 5¼-inch dual-sided optical disk has the capacity to store up to 3000 computed radiographic images with reversible compression. Magnetic tape, DVD, or optical disks clearly provide a space-savings benefit.

With optical electronic storage, digital data do not deteriorate. When such data are retrieved at a later date for image review and/or for copying on film, the reproduced image will be an exact duplicate of the initial image. In addition, any number of copies may be made using the original data, and each copy will be an original image. With this storage medium, computed radiographic image data can be searched for, retrieved, transmitted, or processed with tremendous ease.

Other large-capacity memory devices can be used for digital data storage. Magnetic tape, DVD, and optical disk can serve these storage needs with high degrees of efficiency. Naturally, x-ray film can still be used to store visual analog patterns for image-data filing purposes.

With a computed radiography system, flexibility can exist with the three primary options: (1) maintaining an active image file for display and storage purposes, (2) reviewing data on workstations and using long-term archiving devices for permanent electronic files, and (3) employing a combination of these methods to accommodate individual preferences.

## Characteristics of a Computed Radiographic Image

Three factors are directly responsible for computed radiography image resolution: (1) dimension of the crystals in the imaging plate, (2) size of the laser beam in the reader, and (3) image-reading matrix. Although computed radiography currently offers greater contrast resolution than conventional film, it provides slightly less *spatial resolution* than film. The resolution with computed radiography averages from 2 to 5 line pairs per millimeter (lp/mm), whereas standard film can demonstrate 3 to 6 lp/mm. With further advances in imaging plate phosphor quality, a reduction in the micro beam laser size, and an increase in matrix dimension and image, spatial resolution with computed radiography could become inherently superior to that of conventional film-screen techniques. Present-day diagnoses are not hampered by the current resolution factors. However, chest imaging and mammography will further benefit from the increased spatial resolution that these examinations demand.

**TABLE 34-1**

Capacities of various electronic data storage medium

Medium	Capacity
DLT magnetic tape	35-GB
DVD	
Single side	4.6 GB
Dual side	9.2 GB
Optical disk	
5¼-inch single disk	4-GB
5¼-inch dual disk	8 G-bytes
Multiple-platter optical jukebox	5-10 T-bytes

## Clinical Applications

The sequence of events in computed radiographic imaging in the clinical environment is shown in Fig. 34-6. The process begins at the reception desk, where demographic information (patient name, birth date, sex, identification [ID] number, and examination ordered) is entered into a reception terminal. Transfer of this information to the computed radiography processor may be accomplished directly via a radiology information system (RIS) or health information system (HIS) interface, bar code, magnetic card, or optical scanner.

The radiographer exposes the imaging plate in the same manner as when a conventional film-screen cassette is used. The exposure may be made using a tabletop, mobile, or table/wall Bucky technique. The exposed imaging plate cassette is taken to the control terminal of the computed radiography reader unit. There, the patient demographic and examination information is entered, and the cassette is scanned with the bar code reader. In this way, each specific exposed imaging plate is linked to the correct patient and image data. This step replaces the typical ID camera step in film radiography.

The radiographer inserts the exposed cassette into the computed radiography reader. Once inside, the cassette is automatically opened, and the imaging plate is removed. The imaging plate is scanned, erased, and returned to the cassette or an internal stacker for use on another patient (Figs. 34-6 and 34-7).

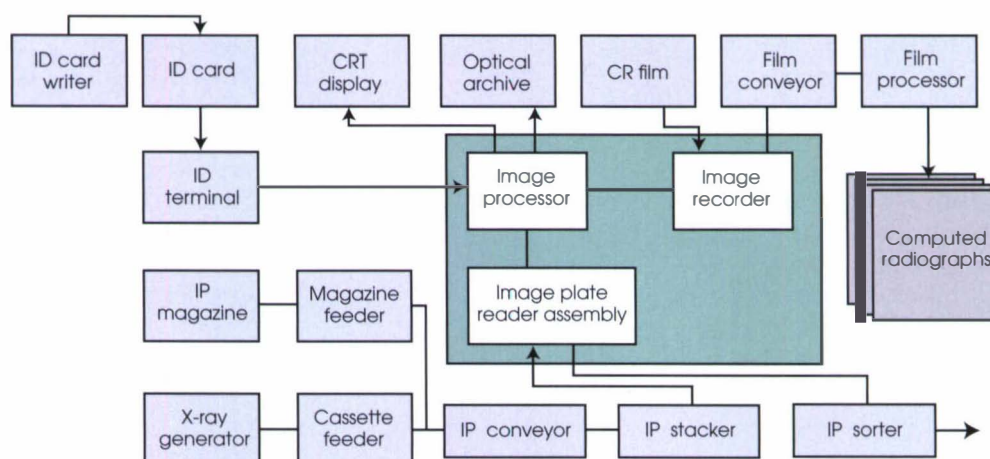


Fig. 34-6 Computed radiography sequence flowchart. (IP, Image processor.)

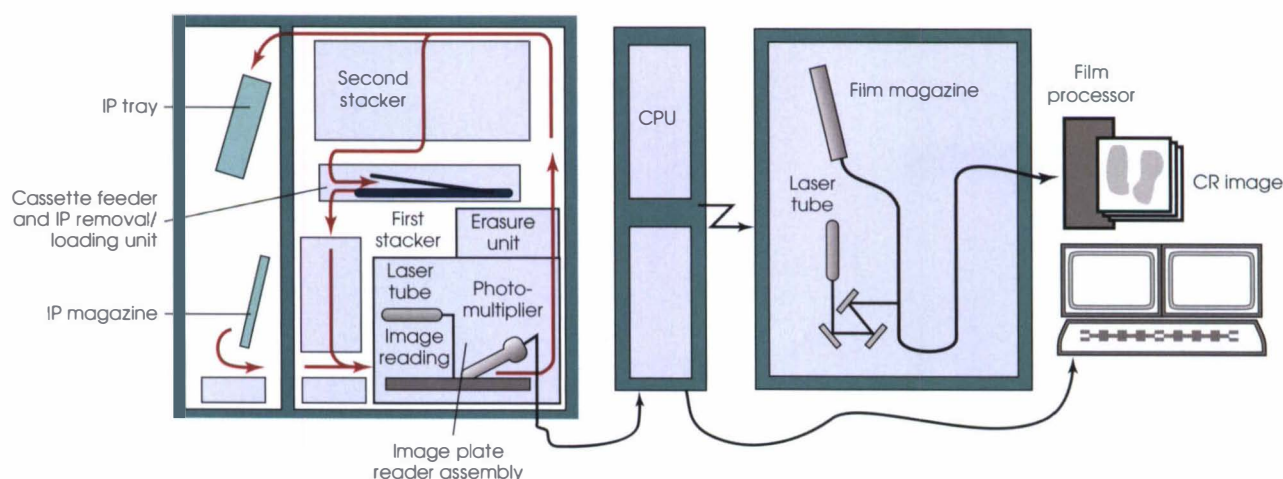


Fig. 34-7 Generalized internal functions and components of a computed radiography system. (IP, Image processor.)

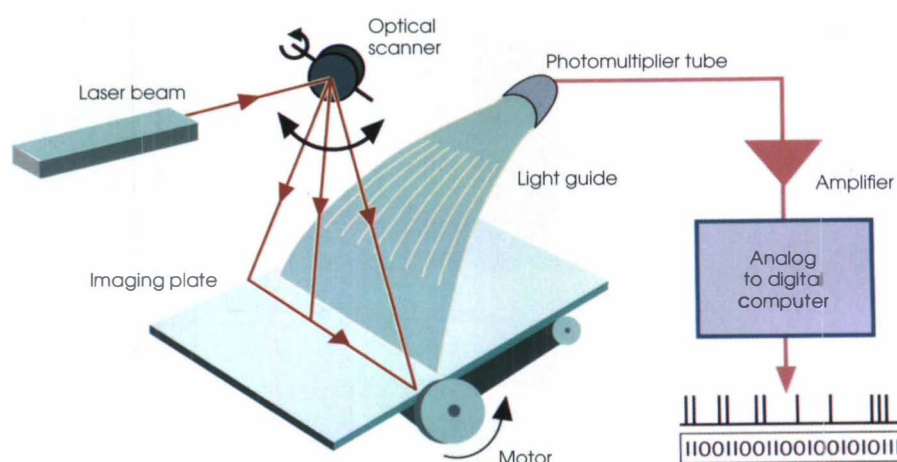


The internal functions of a computed radiography system are illustrated in Fig. 34-7. Inside the system and not apparent to the radiographer is the image plate reader assembly, which scans the imaging plate. The plate is transported through the system at right angles to a red *helium-neon* (633 nm) laser beam or a visible-light semiconductor (680 nm) laser beam until the entire plate is sequentially scanned. When the photostimulable crystals on the imaging plate are exposed to the laser beam, the crystal layer emits the energy in the form of light, which was retained in its "memory" after x-ray exposure. The light intensity emitted is proportional to the amount of x-rays that initially excited the crystal layer. Tracking with the laser beam is a light guide that focuses the emitted light from the imaging plate to a photomultiplier tube. The emitted light energy is converted to an electric signal and is sent to an amplifier and then on to an analog/digital convertor where the analog is converted to a digital data set. The digital data set is related spatially and is proportional in intensity to the original x-ray exposure in each *pixel* of the imaging plate (Fig. 34-8).

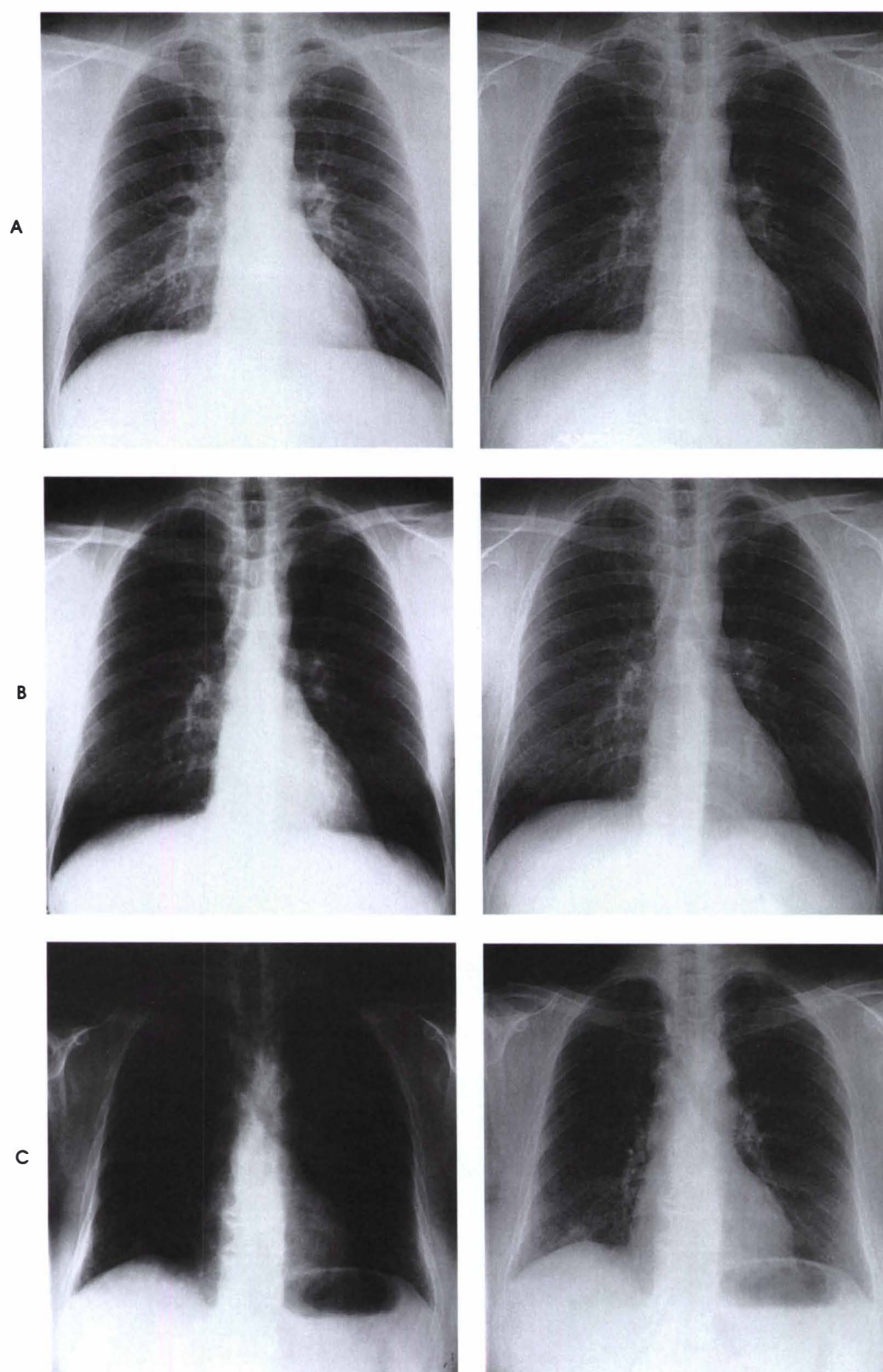
The imaging plates offer wide exposure latitude. During the scanning process a sensitivity adjustment is made to make effective use of this latitude. The data from the imaging plate, as well as the anatomic menu, are examined to analyze the image characteristics and determine the reading sensitivity and exposure latitude. This entire process allows for the wide exposure latitude in computer radiographic imaging.

The computed radiography systems can correct for severely over or under exposed images that on conventional film screen system would be either very dark or light. Errors in technical exposure are virtually eliminated. However it is very important that the technologist understand the correct exposure factors, recommended by the various vendors, required to produce the high quality optimal CR image.

Technical corrections are achieved with computer-aided auto-ranging techniques. Optimized computed radiography display parameters are achieved through *histogram* analysis in proportion to the linear dynamic range of the imaging plates and tailoring the final image characteristics to an agreed-on subjective H&D curve for best display of the anatomic structure(s) of interest.



**Fig. 34-8** Reading of computed radiographic imaging plate and conversion to digital information.



**Fig. 34-9** Six images showing pairs of analog (*left*) and computed radiographs (*right*) acquired simultaneously. Note that despite the widely differing exposure factors, the computed radiographic images do not vary in quality, although the analog radiographs are clearly suboptimal in quality. **A**, Analog radiograph (*left*) and computed radiographic image (*right*), both using exposure factors of 125 kVp, 1 mAs. **B**, Analog radiograph (*left*) and computed radiographic image (*right*), both using 125 kVp, 2.5 mAs. **C**, Analog radiograph (*left*) and computed radiographic image (*right*), both using 125 kVp, 6.3 mAs.

A review of the chest radiographs in Fig. 34-9 is helpful in understanding the effects of this process. Analog and computed radiographic images were simultaneously obtained using a cassette containing both a radiographic film and an imaging plate. Despite technique factors that produced inadequate analog radiographs, all of the computed radiographic images are of consistent and appropriate penetration and quality.

After the exposure of the imaging plate and its subsequent scanning by the laser beam, the image on the plate is erased. The energy remaining on the imaging plate after reading is completely eliminated by exposing the plate to a uniform and specific light source. This light source is either a bright sodium-vapor or high-brightness fluorescent light with both filtered and unfiltered ultraviolet components. The plates are reusable for thousands of times. In fact, plates may well be mechanically destroyed or damaged before any degradation of the crystalline structure is realized.

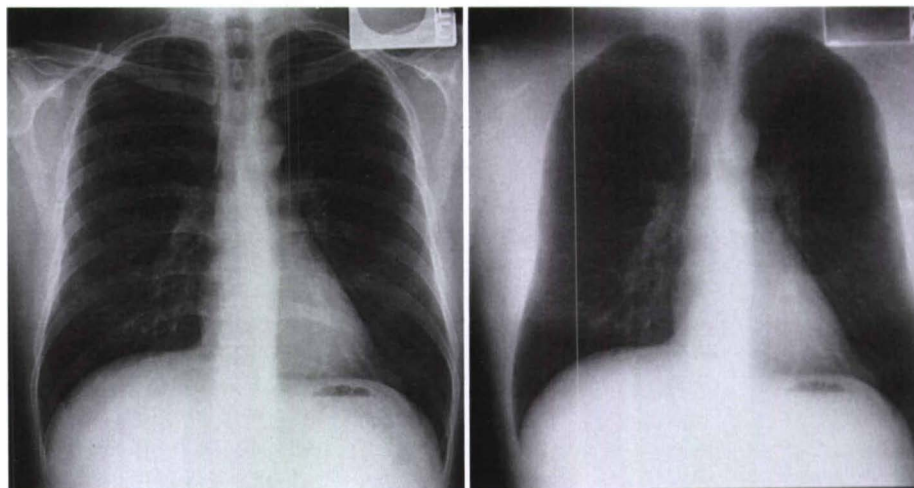
## Other Techniques to Improve Diagnostic Efficacy

In addition to the manipulation of images on a workstation, several other techniques can be used to improve the diagnostic power of computed radiography. These techniques include dynamic range control and energy subtraction.

*Dynamic range control (DRC)* is a processing protocol to set optical density of certain anatomic regions that normally appear as overexposed or underexposed. These regions might exist in high-density or low-density areas. The computer generates a filter (mask) image from the original, and the filter is then superimposed on the original. The result of DRC is better visualization of the mediastinum in chest imaging and better soft tissue display in shoulder and knee images.

*Energy subtraction* is a recently developed type of processing. It requires the use of two imaging plates with a 1-mm copper filter sandwiched between them. The first plate records the full-energy spectrum of the radiation beam. Radiation that passes through the first plate undergoes low-energy filtration (beam hardening) by the copper filter before it enters the second plate. The image recorded by the second plate consists primarily of the high-energy component of the beam; therefore the bone/calcium contrast is markedly reduced over that in the image recorded on the first plate.

A subtraction process, aided by the computer, takes place twice. This provides one image of the soft tissue and a second image of the bone and calcium. In all, three PA chest images are produced: a standard radiograph image, a soft tissue image, and a bone/calcium image. Fig. 34-10 shows a standard image and a soft tissue image.



**Fig. 34-10** Standard computed radiographic chest image (left) and soft tissue image (right) of only lung tissue using the energy subtraction process.



## Clinical Acceptance

Computed radiography is being used in private offices, medical centers, and hospitals for all applications in which conventional projection radiography can be used, including chest, bone, and mobile radiography. It is also being used for contrast-enhanced examinations such as excretory urography and gastrointestinal radiography. Angiography applications are primarily performed using digital radiography (see Chapter 35).

## Quality Assurance Concerns

A positive design feature of a computed radiography system is its ability to minimize image *artifacts*, whether induced from system irregularities or operator errors. However, periodic failures in these safeguards are inevitable and affect image quality.

System *noise*, artifacts, and unevenness in an image are determined by the noise inherent in the imaging plate (structure noise) and reader system (quantum noise). Digital processing errors can create artifacts and density irregularities.

The operator can control several artifacts. Dust on the imaging plate can be seen on the resulting image. It is therefore important to maintain a periodic schedule of cleaning the imaging plate surfaces for quality assurance, just as a similar program of quality control maintenance is used for radiographic intensifying screens. In addition, grids of a particular ratio and line factor are recommended for various examinations. If these recommendations are not followed, a *moiré* pattern of laser light scanning lines or data loss can occur. Scatter radiation is detrimental to the quality of both computed radiographic and conventional film-screen images. Grids must be used when warranted by the examination or the patient's body habitus.

Although computed radiography systems are able to correct for gross technical errors, there is a limit to the minimum dosage required for appropriate penetration and a diagnostic image. The imaging plates require a minimum amount of photon energy and this is supplied by the amount of kilovoltage used for the examination. The various vendors have minimum kVp requirements to help with the necessary photon energy and to help reduce the dosage to the patient. Each institution operating a computed radiography system must establish radiation dose reduction limits. Inadequate radiation doses result in images that demonstrate quantum mottle or areas devoid of data.

## Pitfalls

Correctly produced computed radiography images have few undesirable characteristics, and these will not cause diagnostic problems, even with a relatively inexperienced computed radiography operator. Edge-enhancement artifacts are the primary problems in this type of imaging. In certain circumstances, edge enhancement creates an appearance that may be confused with a pathologic disorder. On the edge-enhanced image a dark band may appear at the interface between structures that differs widely in density. This effect is primarily seen in computed radiographic images involving metal prostheses and barium contrast studies. The dark line of the edge-enhancement artifact is always perfectly symmetric around the dense object, which makes it relatively easy to distinguish from a lesion causing lucency.

## Benefits

When a computed radiography system is used, several benefits are readily apparent. These benefits are discussed in the following sections.

### IMPROVED DIAGNOSTIC ACCURACY AND EXPANDED DIAGNOSTIC SCOPE

With the storage of laser-scanned x-ray images on high-sensitivity imaging plates, minute differences in x-ray absorption are detected, providing highly detailed and easily readable diagnostic information. The wide exposure latitude permits diagnosis of an entire area of interest, allowing imaging from bones to soft tissue with a single exposure. Computer analysis of images can provide increased diagnostic information to assist in the medical treatment of a patient.

### X-RAY DOSAGE REDUCTION

X-ray dosage reduction is dependent upon the type and speed of the conventional film/screen system in place at the institution converting to computed radiography. If the institution is utilizing a 400-speed film/screen system, then the CR imaging plates will require approximately 15% to 25% more exposure. It is important that the technologist understands that the best way to increase the exposure is to increase the kV to minimize the increase dose to the patient. The increase in kV is also necessary to increase the number of photons reaching the imaging plate, which in turn produces a more optimal CR image. If the institution is utilizing a 200 or 100 speed film/screen system then the technique will need to be reduced thus decreasing dosage to the patient. The CR vendors have CR technique guides that should be followed to ensure the proper exposure is used to minimize dose to the patients.

### REPEAT RATE REDUCTION

Because of the wide technique latitude of the computed radiography system, technical errors are easily corrected to provide prime diagnostic information. When a film-screen combination is used, technical errors in either direction can markedly degrade the image quality. Technical errors have much less effect on the final quality of a computed radiographic image. This benefit obviously increases *throughput* and reduces the patient's discomfort because it lessens the need to repeat the examination. The technical latitude of computed radiography is a tremendous asset in the area of mobile or portable radiography.

### TELERADIOGRAPHIC TRANSMISSION

Image plate reader devices can be linked via dedicated phone lines, microwave transmission, or other *telerradiographic* means to centralize the review of image data. This means of image sharing is an obvious benefit to affiliated hospitals or clinics that are separated by large geographic distances but share professional staff. Teleradiology could also provide immediate consultation with specialists, which benefits not only the patient but also the level of efficiency of the institution.

### PICTURE ARCHIVE AND COMMUNICATION SYSTEM

Many radiology departments are contemplating the installation of a *picture archive and communication system (PACS)* for the immediate or near future. Many others, however, are hesitating to implement PACS because of concerns about multimodality/multivendor interfacing, as well as the requirement that conventional projection radiography (which represents approximately 70% of a radiology department's volume) be digital format compatible. Computed radiography is the link needed for PACS. With computed radiography, all imaging modalities can now be integrated and can share processing, display, and archiving ventures.

PACS will allow radiology department to finally move to the filmless environment and reduce the cost of purchasing radiographic film. However the initial cost of purchasing all the computer hardware necessary to eliminate the need for film is still quite high. Despite the fact that the first experiments with PACS took place in the early 1980s, it has not been until the late 1990s that clinically useful, routinely operating PACS systems have been installed. There are numerous reasons for an institution to evaluate the opportunity to install a PACS system, with the ultimate goal of improving patient care. The advantages and disadvantages of PACS are summarized in Box 34-2. Institutions that have installed PACS and are currently utilizing the systems indicate that the advantages outweigh any disadvantages and that the technology and experience will eventually reduce or even eliminate the downside.

#### BOX 34-2

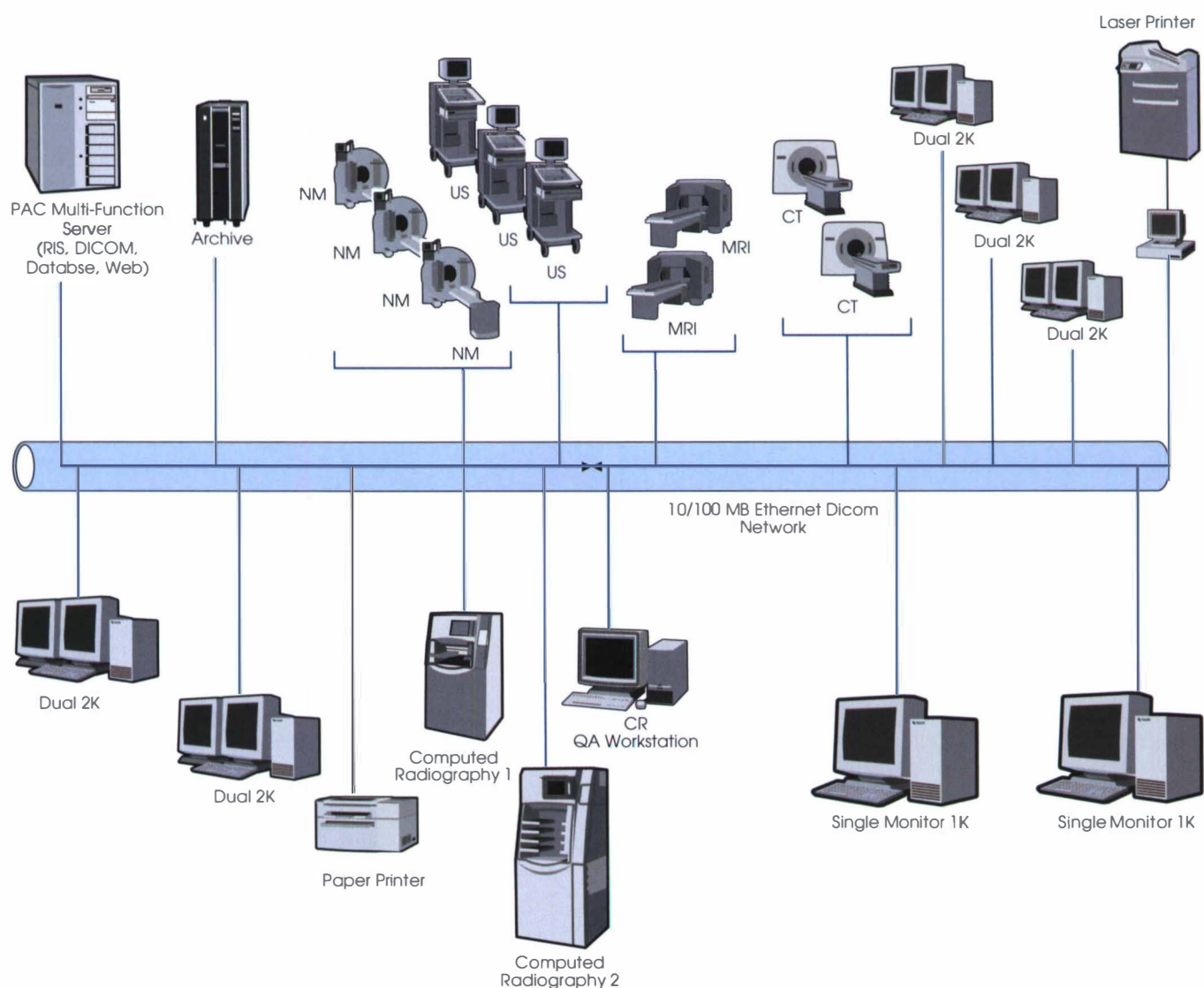
##### Advantages and disadvantages of PACS

Advantages of PACS include:

- Near complete elimination of lost films
- Quicker access to prior examinations
- Ability to compare multi-modality images on same patient
- Availability of full digital data when interpreting exams
- Ability for a single exam to be viewed in multiple locations at the same time
- Potential improvements in workflow

Disadvantages of PACS include:

- High initial costs
- Lower reliability than film-based systems
- Learning a new paradigm for radiologist interpretations of examinations
- Potential decrease in diagnostic ability



**Fig. 34-11** A diagram of a typical PACS network demonstrating all the different imaging modalities connected throughout a medical system.



Currently less than 1% of the hospitals in the United States are using a complete PACS system and are entirely filmless, with the exception of mammography. The institutions that are completely PACS report that the retake rate is much reduced, some improvements in workflow are noted, and with a fast reliable archive they are able to store and retrieve digital images much faster.

The effect of a PACS system on an institution, once installed and operational, may be difficult to predict. There may be unintended and unforeseen effects of the PACS operation on the radiology department and interacting departments. Improvements in efficiency in one part of an institution may reveal bottlenecks in another. Another effect of a completely digital department with PACS is work shifting. For example, the number of personnel in the film library may be reduced as work requirements are eliminated by PACS. However these same personnel may be needed to perform a new task related to the PACS system such as merging miss-marked patient examinations or the deletion of duplicate files not automated by the PACS system.

Important for the installation of a PACS system is thorough evaluation of the integration of the PACS network with other information systems within the institution. From the deciding that there is a need for PACS within an institution to the actual installation there is a continuum of many steps and decisions that cannot be taken lightly. If the process is not viewed as a continuum, the resulting PACS system may, to the detriment of the institution, reflect the underlying disorganization of planning. The majority of institutions anticipating the installation of PACS utilize consultants, view many plans, visit several sites currently using a PACS system, and form large committees comprised of all the departments that will be affected by the PACS system before purchasing such a system. There are many possible designs available for the department to review as they work to establish a PACS system of their own. Figure 34-11 illustrates one such design.

#### DEPARTMENT EFFICIENCY

The computed radiography system eliminates all darkroom work. This factor plus the previous benefits ultimately increase departmental efficiency.

## Conclusion

Computed radiography will improve both the operational and diagnostic efficiency of radiology departments. With the placement of conventional projection radiography in digital format, computed radiography forms the keystone for PACS. Computed radiography improves the efficiency of conventional projection radiography by providing consistent image quality, decreasing repeat exposure rate, minimizing patient radiation exposure, and decreasing lost images. By realizing such benefits, many departments have already found that computed radiography is a justifiable long-term investment.

## Definition of Terms

**analog** Any information represented in continuous fashion rather than discrete units.

**analog-to-digital conversion** Process of converting a continuous (analog) signal to discrete (digital) units.

**artifacts** Observable, undesirable image features resulting from faulty image processing techniques.

**barium fluorohalide (BaFX:Eu<sup>2+</sup>)** Barium fluorohalide with europium, the photostimulable phosphor used on CR image plates.

**cathode ray tube (CRT)** Electron tube (like a television tube) that makes the computer output visible; sometimes called a *video display unit (VDU)*.

**computed radiography (CR)** Digital imaging process using a photostimulable chemical plate for initial acquisition of image data; the display parameters of the image can be manipulated by a computer at a later time.

**default** Parameters by which the system operates; if no changes in instructions are made by the operator, the preset operating parameters or controls of the system prevail.

**digital** Any information represented in discrete units (also see *analog*).

**dual energy imaging** X-ray imaging technique in which two x-ray exposures are taken of the same body part using two different kilovoltages; the two images are processed to remove image contrast resulting from either soft tissue or bone.

**DVD** Digital video disk is most common definition for this acronym. A DVD is a type of read only memory compact disc, approximately the same size as a compact disc (CD), but with much larger storage capacity. Each side of the DVD disc can contain two data layers, one embedded beneath the other.

**dynamic range** Orders of magnitude over which the system can accurately portray information.

**dynamic range control** Image-processing algorithm for image enhancement that provides a wide diagnostic field, allowing visualization of bone and soft tissue in a single image display.

**edge enhancement** Technique of setting the spatial frequency response so that structures of a given type, usually bones, stand out in bold relief.

**energy subtraction** Processing techniques used in computed radiography that include a dual-exposure method, which requires irradiation with two different x-ray energies, and a single-exposure method, which requires only one x-ray irradiation but in which the x-ray energies are separated by inserting a copper filter between two imaging plates.

**gradation processing** Technique of setting the range of values over which an image is displayed; similar to the window setting in CT; allows selection of a wide range of values to display structures with widely differing densities or a narrow range to display structures close together in density; for example, a body part such as the mediastinum.

**gray-level display** Number of possible shades of gray in a digital image; this number depends on the pixel depth of the digital acquisition devices and the display units. Acquisition devices and display units with 8-bit pixel depth capabilities give 256 possible shades of gray, whereas units with 10 bit pixel depth give 1024 possible shades of gray.

**helium-neon (633 nm) laser** Intense, coherent beam of light in the red wavelength

**histogram** Graphic representation of the frequency distribution of gray levels, which represent the anatomy in a computed radiographic image (see Chapter 32, Fig. 32-13, for an example).

**image plate reader** Component of the computed radiography system that scans the image plate with a laser and converts the analog information on the image plate into an electric signal; an analog-to-digital converter then changes the electric signal to a digital signal.

**imaging plate** Image capture portion of computed radiography; appears the same as a screen in the film-screen environment except that the imaging plate is a photostimulable phosphor with the ability to "capture" an x-ray image as electrons are stored in stable traps within the phosphor compound.

**latent image** Nonobservable representation of a structure such as the varied energy changes inherent in the crystalline structure of imaging plates.

**matrix** Gridlike pattern of an image composed of a certain number of pixels both in the horizontal and the vertical planes.

**megabyte (MB)** 1000 bytes.

**moiré** Fine network of wavy lines that have a watered appearance on the displayed image.

**noise** Image appearance as graininess on monitors and printed radiographic images.

**photostimulable phosphor** Special luminescent material that stores x-ray energy and emits light proportional to the stored x-ray energy when stimulated by energy such as visible light from a laser.

**picture archive and communication system (PACS)** System of computers linked together via a network to store and transmit digital images throughout the network; can be within a hospital but may also include remote sites.

**pixels (picture elements)** Small squares that form the image; pixels have depth in bits usually 8, 12, 15; the greater the pixel depth, the larger the gray scale.

**spatial frequency response** Sharpness of image that controls how prominently the "edges" are seen in one structure of one density compared with the "edges" in an adjacent structure of another density. In the computed radiography system the technique is called "unsharp masking"; an unsharp (blurred) image is used as the mask image to enhance the spatial frequency response.

**spatial resolution** How small an object that can be detected by an imaging system and how close together two similar objects can be and still be identified as separate objects; unit of measure usually used is line pairs per millimeter (lp/mm); for example, if the spatial resolution is 10 lp/mm, it means that 10 lines per millimeter can be distinguished as discrete lines, but if there are more than 10 lines per millimeter, some lines will "run together" and appear to be a single line.

**teleradiography** Ability to send and receive radiographic images over telephone lines from one institution to another.

**throughput** Rate at which items can be processed through a system; originally a systems analysis term but now commonly used in medicine. If a radiology department can perform a maximum of 60 chest radiographs per hour, this is the maximum throughput for chest radiographs.

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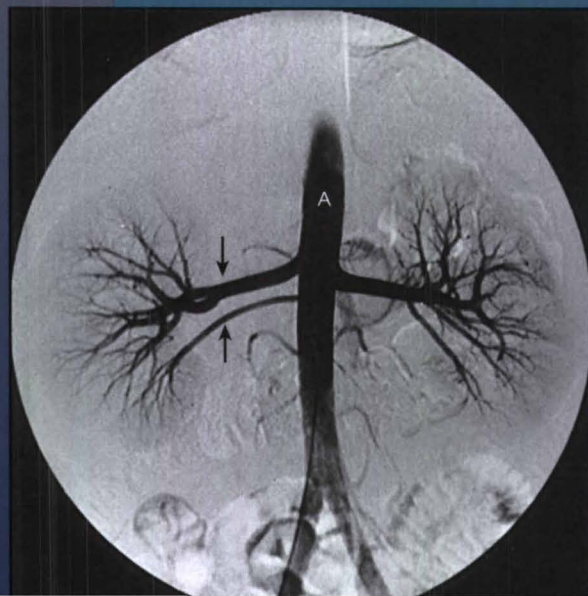
# DIGITAL ANGIOGRAPHY AND DIGITAL SPOT IMAGING

WALTER W. PEPPLER

Intraarterial DSA image of abdominal aorta (A), showing one renal artery on the left and two renal arteries on the right (arrows). All renal arteries are widely patent.

## OUTLINE

Principles of digital angiography  
and digital spot imaging, 374  
Historical development, 374  
Equipment and apparatus, 375  
Performing digital subtraction  
angiographic procedures, 376  
Image postprocessing, 378  
Clinical applications, 380  
Conclusion, 382  
Definition of terms, 383



## Principles of Digital Angiography and Digital Spot Imaging

Digital electronic technology has increased the speed of image processing and decreased costs to the point where totally electronic radiographic image detection, storage, and display have largely replaced film in a number of procedures. More importantly, radiographic images stored in a digital memory can be manipulated in ways that are impossible with traditional film-screen technology. Such manipulation enables the radiologist to isolate image information that is too low in image contrast to be recognized on a conventional radiograph. The ability to “see” what previously had been invisible has opened new areas for radiographic study.

## Historical Development

Following the introduction of the computer in medicine, the practice and development of radiologic procedures expanded rapidly.<sup>1</sup> The acquisition of digital images from a combination *image intensifier/television (II/TV)* system was first introduced as *digital subtraction angiography*\* (DSA). DSA was developed during the 1970s by groups at the University of Wisconsin, the University of Arizona, and the Kinderklinik at the University of Kiel, Germany. This work led to the development of commercial systems, which were introduced in 1980. Within the next few years many manufacturers of x-ray equipment introduced DSA products. After several years of rapid change the systems evolved to those available today. The primary changes since the introduction of DSA include improved image quality, a larger pixel *matrix* (up to  $1024 \times 1024$ ), and fully digital systems.

<sup>1</sup>The chapter “Computer Fundamentals and Applications in Radiology” has been deleted from this edition. For those interested in reading more about computer fundamentals, please see Volume 3, Chapter 32 of the eighth or ninth editions of this Atlas.

\*Almost all italicized words on the succeeding pages are defined at the end of this chapter.

## INTRAVENOUS VERSUS INTRAARTERIAL INJECTION

The most notable change in DSA was not in equipment design but in clinical practice. The initial success and promise of DSA were predicated on the intravenous (IV) injection of contrast media. IV procedures were less risky and less expensive than the intraarterial procedures used for conventional angiography (see Chapter 26), and they could be performed on an outpatient basis. This was advantageous because conventional intraarterial film *angiography* usually required an overnight hospital stay. In addition, IV DSA was less painful for the patient.

However, IV DSA did have serious drawbacks. Cardiac motion, diaphragmatic motion, bowel peristalsis, swallowing, and coughing all caused image *artifacts*. In patients with decreased cardiac output, the contrast bolus became seriously diluted; as a result, examinations were frequently nondiagnostic. In addition, large volumes of contrast material were required for the IV method of DSA, and contrast toxicity became a serious consideration. Finally, because all arteries in the region of interest (ROI) were opacified, superimposition made the diagnosis of arterial pathology difficult.

The standard of practice quickly evolved to performing DSA using intraarterial injection of contrast material. Because the examination was performed intraarterially, a smaller volume of more dilute contrast medium was required. With the contrast material injected intraarterially near the ROI, patient motion and the attendant image degradation occurred less frequently. The evolution of smaller catheters (4 to 5 Fr) allowed outpatient arteriography to be performed safely. After the introduction of *nonionic contrast media*, patients experienced less discomfort (nausea and vomiting); the incidence of severe life-threatening reactions also decreased significantly, with nephrotoxicity remaining about the same.

However, the main reason for the transition to intraarterial injection is the very significant improvement in image quality. IV injection of contrast media produces not only poorer image quality but also more variable results than those obtained routinely using intraarterial injections.



## DIGITAL SPOT IMAGING

Image quality has improved to the point that the digital imaging system, originally developed for subtraction images, now has sufficient image quality for *unsubtracted imaging* applications. In the general radiographic/fluoroscopic (R/F) suite, unsubtracted digital images are of sufficient image quality to replace traditional spot-film devices based on film. In addition to the excellent image quality, the ease of use and rapid display of images on a digital system are extremely advantageous. Images are available on the monitor immediately, with no need to wait for film to be processed or cassettes to be changed. The digital nature of the image data also lends itself to electronic archiving and transmission of the images. Digital spot radiography is on the verge of becoming commonplace. In the digital angiography suite, *subtraction* is now viewed as an important but optional adjunct to image processing.

Digital imaging suites can also serve multiple purposes. X-ray equipment manufacturers are producing equipment that can be used, depending on optional components, for general R/F, angiographic, and interventional procedures. The equipment requirements for unsubtracted applications are virtually identical to those for DSA except that many of the *postprocessing* options are not necessary. However, regardless of the added features, the systems share the same basic image acquisition equipment and image quality, which are described in the next section.

## Equipment and Apparatus

An II/TV system (fluoroscopy) can be used to form images with little electrical interference, to provide moderate resolution, and to yield diagnostic-quality images when combined with a high-speed *image processor* in a digital angiography (DA) system (Fig. 35-1).

The procedure room is much like a standard angiographic suite, and the fluoroscopic equipment operates in the conventional way. However, the following brief review helps to explain the DA system. The input surface of the *image intensifier* is coated with an x-ray-sensitive phosphor, typically cesium iodide (CsI). The phosphor is contained within a vacuum and enclosed in glass. X-rays that are absorbed by the CsI *input phosphor* emit visible light that is converted to electrons within the image intensifier. The electrons, proportional to the amount of radiation absorbed, are electronically amplified and accelerated across the image tube and are then absorbed by the *output phosphor* of the image intensifier. The output phosphor, approximately 1 inch (2.5 cm) in diameter, emits light when it absorbs electrons. The resulting light intensity is 5000 to 10,000 times brighter than if the CsI phosphor had been used alone.

The television camera is focused onto the image-intensifier output phosphor and converts the light intensity into an electrical signal. The camera forms an image by electronically scanning a photosensitive *semiconductor*, called the *target*, on which the light has been focused. The presence of light on a small portion of the target changes the electrical properties in that target region. These changes are detected by the television camera.

An image is synthesized line by line by the scanning of a narrow electron beam across the television target in up to 1024 parallel lines every one thirtieth of a second. With normal fluoroscopic operation the video image is displayed on a television monitor. The scanning rate is so fast that the human eye does not notice the scanning process but sees a two-dimensional image on the television screen. The images are called *frames* and are presented at a rate of 30 per second.

In a digital imaging system each of the television lines is further divided into segments called *pixels* (*picture elements*). The electronic video signal corresponding to each pixel is *digitized* and stored in a digital memory. Typically each line is divided into 512 or 1024 pixels, and the digitized value (gray level) assigned to each pixel is usually in the range of 0 (representing black) to 1023 (white). The image in *memory*, which is made up of a total of  $512 \times 512$  pixels or  $1024 \times 1024$  pixels (the number of lines multiplied by the number of pixels per line), is also stored on a digital disk for later review, manipulation, and analysis.

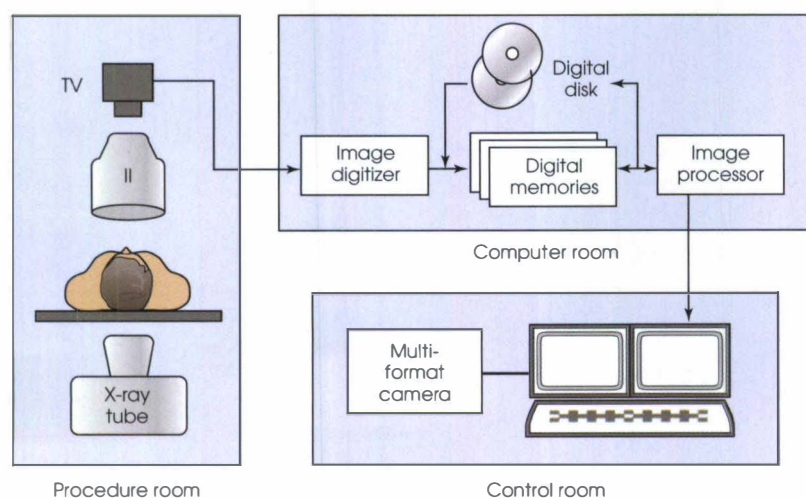


Fig. 35-1 Block diagram of a digital angiography (DA) system.

The *image processor* consists of a computer and image processing hardware. The computer controls the various components (e.g., memories, image processing hardware, and x-ray generator), and the image-processing hardware gives the system the speed to do many image processing operations in *real time*. The computer and the operator communicate via a keyboard with special function keys, a mouse, and/or a touch-sensitive screen.

The control room is usually separated from the procedure room and has a leaded glass window for observation (Fig. 35-2). Typically one video monitor is located on the operator's console, and another one is in the procedure room next to the fluoroscopic monitor. A computer monitor at the operator's console is used for communicating with the computer. The video monitors display the images in real time as the images are obtained during the imaging sequence. At a later time, images (*hard copies*) are produced using a multiformat camera or laser imager.

## Performing Digital Subtraction Angiographic Procedures

A DSA study begins with catheter placement performed in the same manner as for conventional angiography. Injection techniques vary, but typically 15 to 20 ml of iodinated contrast medium is injected at a rate of 10 ml/sec. An automatic pressure injector is used to ensure consistency of injection and to facilitate computer control of injection timing and image acquisition.

The intravascular catheter is positioned using conventional fluoroscopic apparatus and technique, and a suitable imaging position is selected. At this point an image that does not have a large dynamic range should be established; no part of the image should be significantly brighter than the rest of the image. This can be accomplished by proper positioning, but it often requires the use of compensating filters. The filters can be bags of saline or thin pieces of metal inserted in the imaging field to reduce the intensity of bright regions. Metal filters are often part of the collimator, and water or saline bags are placed directly on or adjacent to the patient.

If proper placement of compensating filters is not performed, image quality is reduced significantly. The reason is that the video camera operates most effectively with video signals that are at a fixed level. Automatic controls in the system adjust the exposure factors so that the brightest part of the image is at that level. An unusually bright spot satisfies the automatic controls and causes the rest of the image to lie at significantly reduced levels, where the camera performance is worse. An alternative to proper filter placement is to adjust the automatic sensing region, similar to automatic exposure control (AEC) for conventional radiography, to exclude the bright region. This solution is less desirable than the use of compensating filters, and it is not always effective for some positions of the bright spot on the image.

As the imaging sequence begins, an image that will be used as a subtraction mask (without contrast medium) is digitized and stored in the digital memory. This mask image and those that follow are produced when the x-ray tube is energized and x-rays are produced, usually one exposure per second at 65 to 95 kVp and between 5 and 150 mAs. The radiation dose received by the patient for each image is approximately the same as that used for a conventional radiograph. Images can be acquired at variable rates, from one image every 2 to 3 seconds up to 30 images per second.



Fig. 35-2 Operator console of digital angiography system with procedure room in the background.

(Courtesy Philips Medical Systems, Shelton, Conn.)



The *acquisition rate* can also be varied during a run. Most commonly, images are acquired at a faster rate during the passage of iodine contrast medium through the arteries and then at a reduced rate in the venous phase, during which the blood flow is much slower. This procedure minimizes the radiation exposure to the patient but provides a sufficient number of images to demonstrate the clinical information. Each of these digitized images is electronically *subtracted* from the mask, and the subtraction image is amplified (contrast enhanced) and displayed in real time so that the subtraction images appear essentially instantaneously during the imaging procedure (Fig. 35-3). The images are simultaneously stored on a *digital disk* or *videotape recorder*. Videotape recorders are often used when images are acquired at a rate of 30 per second. Real-time digital disks capable of recording images at a rate of 30 per second are expensive and are usually restricted to cardiac applications, in which high imaging rates are more common.

Some DSA equipment allows the table or the II/TV system to be moved during acquisition. The movement is permitted to "follow" the flow of iodine contrast material as it passes through the arteries. Sometimes called the "bolus chase" method, this technique is particularly useful for evaluating the arteries in the pelvis and lower limb. Previously, several separate imaging sequences would be performed with the II/TV positioned in a different location for each sequence, but this method required an injection of iodine contrast material for each sequence. The bolus chase method requires only one injection of iodine, and the imaging sequence follows (or "chases") the iodine as it flows down the limb. The imaging sequence may be followed by a duplicate sequence without iodine injection to enable subtraction.

*Misregistration*, a major problem in DSA, occurs when the mask and the images displaying the vessels filled with contrast medium do not exactly coincide. Misregistration is sometimes caused by voluntary movements of the patient, but it is also caused by involuntary movements such as bowel peristalsis or heart contractions. Preparing the patient by describing the sensations associated with contrast-medium injection and the importance of holding still can help to eliminate voluntary movements. It is also important to have the patient suspend respiration during the procedure. Compression bands, glucagon, and cardiac gating can be effective in reducing misregistration caused by involuntary movement.

During the imaging procedure the subtraction images appear on the display monitor. Often a preliminary diagnosis can be made at this point or as the images are reviewed immediately after each exposure sequence. However, a formal reading session occurs after the patient study has been completed; at that time the final diagnosis is made.

Some *postprocessing* (described in the next section) is performed after each exposure sequence to improve visualization of the anatomy of interest or to correct misregistration. More involved postprocessing, including quantitative analysis, is performed after the patient study has been completed. The processed images are available on the computer monitor for review by the radiologist. Because the images are digital, it is possible to store them in a *picture archive and communication system (PACS)* (see Chapter 34). With PACS, images can be archived in digital format on various computer devices, including magnetic tape and optical disk. The images can also be transmitted via a computer network throughout the hospital or to remote locations for consultation with an expert or the referring physician. As an alternative to digital storage and reading, hard-copy images may be produced using a *laser printer* or *multiformat camera*, with several images appearing on each radiograph. When produced, they are normally used for the formal reading session and are also kept for archival purposes.

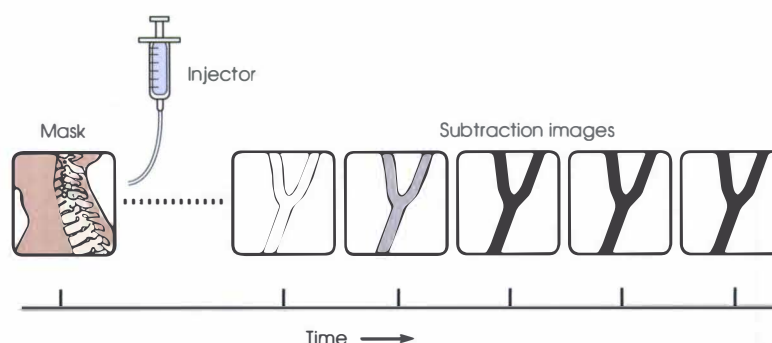


Fig. 35-3 Schematic representation of a DSA imaging sequence.



## Image Postprocessing

### CONTRAST AND BRIGHTNESS ADJUSTMENT

After the images have been obtained and stored on a disk, several methods can be used to manipulate, or postprocess, the images. The most common is to adjust the contrast and brightness to produce an optimum display of the image. The contrast and brightness adjustments are equivalent to the window and level adjustments performed on CT images (see Chapter 33) or MRI images (see Chapter 36). The terms *contrast* and *brightness* are often used for DSA because of the similarity to adjusting these elements on a television set.

### REMASKING

Another common postprocessing task is correction of misregistered images. The most effective way to fix misregistration is simply to *remask* the image. In remasking, another mask image is chosen that is properly registered with the image of interest. The procedure is usually simple. Rather than choosing new masks one at a time (which may or may not work), the operator selects as the mask the image that contains the maximum iodine signal. Then the operator looks for a "live" image (in this case, without iodine) that subtracts from the mask without misregistration. The reversal of the role of the images changes the polarity of the subtraction image (i.e., from white contrast to black contrast). However, the original polarity can be restored by pressing the contrast inversion button. This procedure usually produces an acceptable image with minimal effort (Fig. 35-4).

### PIXEL SHIFTING

In some runs an acceptable mask cannot be found. One way to salvage such runs is by *pixel shifting*. In this technique one of the images is shifted with respect to the other to compensate for the movement of the patient between the two images. In many cases, shifts of a fraction of a pixel are necessary to obtain proper registration. Most processors allow at least horizontal and vertical translation, and some also permit rotation. Pixel shifting can be a tedious procedure that requires a great deal of patience. In addition to many possible pixel shifts, several combinations of mask and live images may have to be tried. Pixel registration routines that automatically register (shift) the images are available and are often quite effective.

### UNSUBTRACTED IMAGES

Obtaining adequate registration of the mask and iodinated images may be impossible in some situations, such as when patients are uncooperative or bowel peristalsis causes problems. In such cases, the use of unsubtracted images may be the best approach. Unsubtracted images are planned from the outset for certain imaging sequences, such as pulmonary angiography, in which motion cannot be completely eliminated. In these cases, contrast injection with a greater iodine concentration or volume may be used.

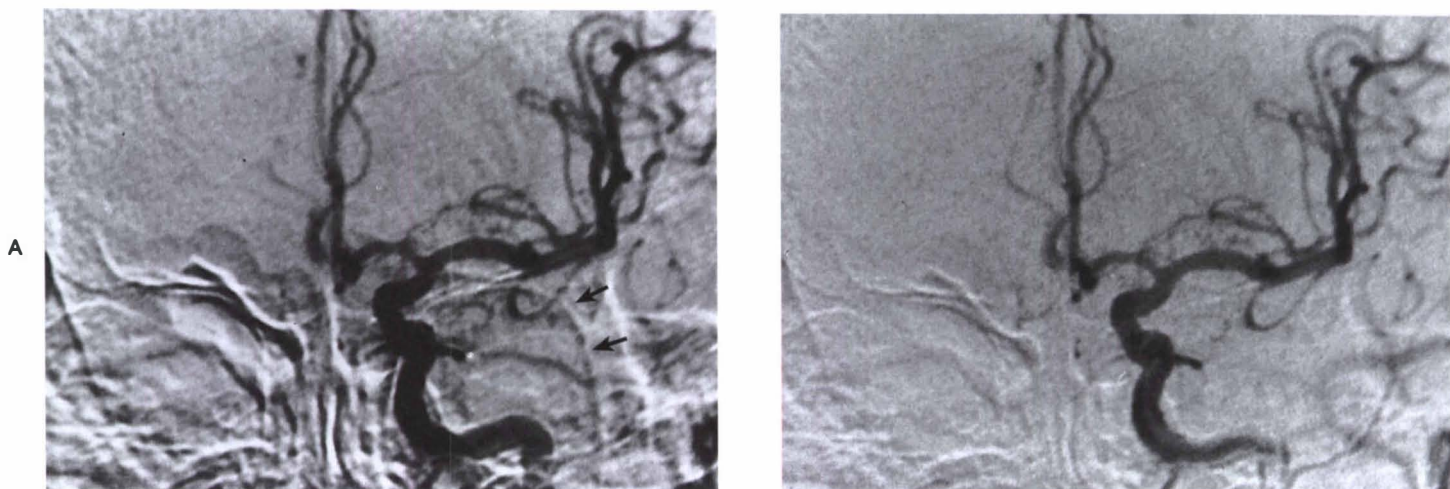


Fig. 35-4 Intraarterial DSA angiogram of the intracranial arteries. **A**, Misregistration artifacts. **B**, Same image after remasking. Note the significant improvement in misregistration artifacts, particularly in the region of the orbit (arrows).

### VIEW TRACING

A series of images acquired during the passage of contrast medium can be combined into one image that reveals the entire flow of iodine. First the series of images must be selected. The chosen beginning image is one in which the iodine has first reached the artery, and the last image is one showing that the iodine has filled the distal parts of the arterial tree. The *view trace* function takes the images from the first to the last and, for each pixel in the image, finds the maximum contrast for that pixel. The composite image then displays each pixel at the maximum contrast it contained during the chosen sequence. The resulting image looks as though the contrast material is spread throughout the entire arterial structure simultaneously.

### EDGE ENHANCEMENT

Using *edge enhancement*, also called *unsharp masking*, the edges of vessels can be accentuated (or enhanced) so that small details can be made more obvious. Various amounts of edge enhancement can be obtained. However, greater amounts of edge enhancement also accentuate the noise in the image.

### IMAGE ZOOM

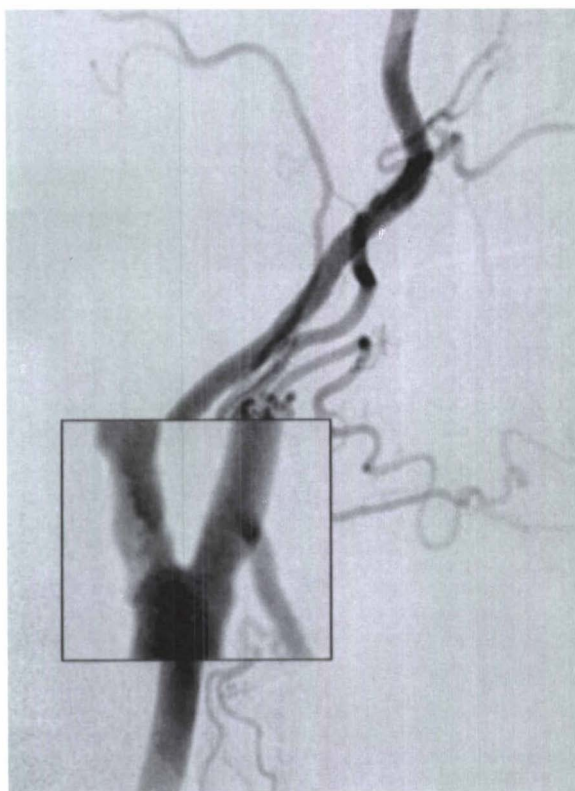
Another postprocessing option is to magnify, or *zoom*, the image. Zooming the image increases the size of a part of the image to make some subtle feature more visible. One option is to zoom a part of the image to occupy the entire screen. The image can be “panned” in all directions so that the parts of the image outside the screen area can be seen. Another option is to display a magnifying glass region on the image. The part of the image within this region appears larger, as if viewed through a magnifying glass placed on the screen (Fig. 35-5). The size of the magnifying region is adjustable, and the region can be moved about the image. It should be noted that neither of the methods increases the image resolution. They simply present the same information as a larger image.

### LANDMARKING

In *landmarking*, a small amount of the original image is put back into the subtraction image. This common procedure gives surgeons anatomic landmarks so that they can more accurately locate structures in the image. Without the landmark information it is difficult to locate the structures because the background has been so effectively eliminated. Only a fraction of the mask is added, however, so that the mask does not overwhelm the subtraction image. As an alternative to landmarking, an unsubtracted image may be printed on the same film as the subtraction images and used as a reference.

### ANALYTIC TOOLS

Most image processors have a wide variety of analytic tools, including methods to measure distances, quantitate vessel stenoses, calculate ventricular ejection fraction, and measure blood flow. These tools are used regularly for cardiac studies. They are also used often for neurologic studies and occasionally for vascular studies.



**Fig. 35-5** Image of carotid artery (see Fig. 35-6) demonstrating a magnifying-glass type of image zoom.





Fig. 35-6 DSA image of common carotid artery, demonstrating stenosis (arrow) of internal carotid artery.

## Clinical Applications

### INTRAARTERIAL DIGITAL SUBTRACTION ANGIOGRAPHY

Nearly all peripheral and cerebrovascular arteriography is performed with intraarterial DSA (Figs. 35-6 to 35-8). Digital unsubtracted imaging is used whenever misregistration is a problem. For example, in patients with gastrointestinal bleeding, diaphragmatic motion or bowel peristalsis can cause severe image degradation of subtracted images.

Patients with peripheral vascular disease typically undergo intraarterial DSA examination of the infrarenal abdominal aorta, pelvic vessels, and runoff vessels. The intraarterial DSA method permits the identification of small vessels in the lower limbs of patients with severe peripheral vascular disease (Fig. 35-9). Some of these patients have been able to undergo a distal bypass procedure or angioplasty rather than amputation.

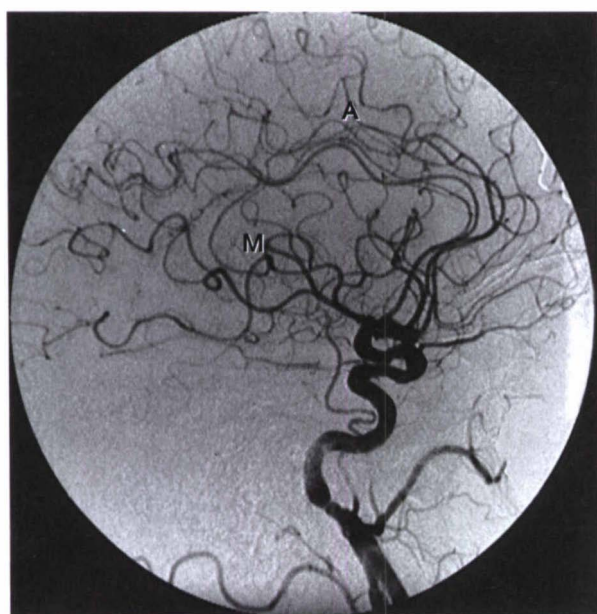


Fig. 35-7 Intraarterial DSA image of the intracranial vasculature showing patent anterior (A) and middle (M) cerebral arteries.

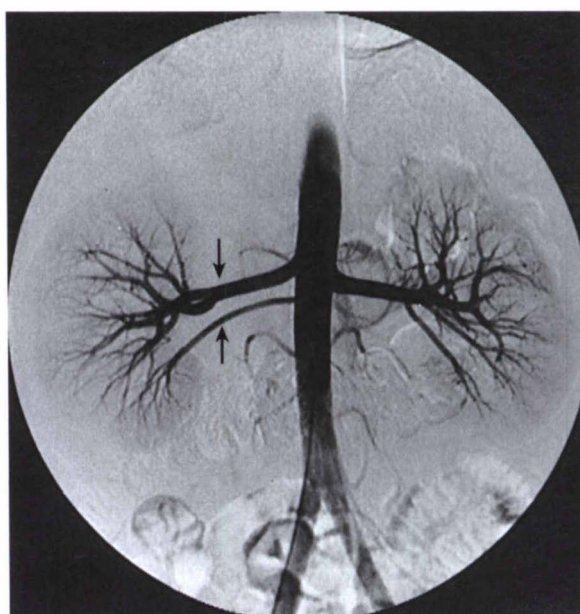


Fig. 35-8 Intraarterial DSA image of abdominal aorta, showing one renal artery on the left and two renal arteries on the right (arrows). All renal arteries are widely patent.



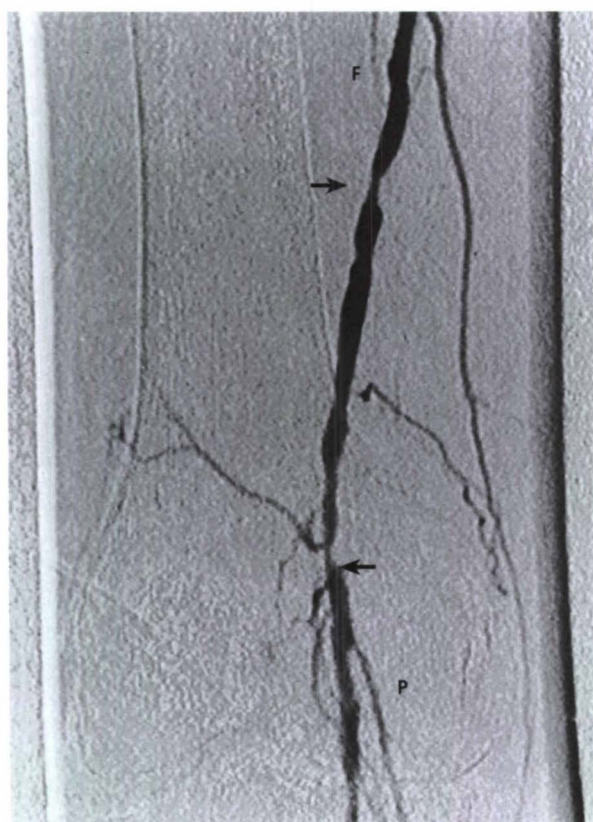
The intraarterial DSA approach can also be applied to pulmonary arteriography. For this examination a catheter is placed within the main pulmonary artery. Consequently, only a small amount of contrast medium must be injected, and a rapid framing sequence (6 frames/sec to 15 frames/sec) is often used. Alternatively, electrocardiographic triggering can be used with lower imaging rates. This application of the intraarterial DSA approach is particularly helpful in the patient with severe pulmonary arterial hypertension who is at significant risk from the high-rate, high-volume contrast injection used for standard pulmonary arteriography.

### ROAD MAPPING

The intraarterial DSA approach has also resulted in the evolution of the *road map technique*. Most interventional radiologists use this technique routinely in the performance of angioplasty. The intraarterial road map technique provides the angiographer with a real-time continuous subtraction on the fluoroscopic monitor during a procedure. Contrast medium is injected while the subtraction mask is obtained; then the fluoroscopic images are subtracted continuously from the mask. The stationary anatomy is canceled, but the iodinated arteries remain. When the catheter is advanced, it appears on the monitor along with the iodinated arteries, which act as a road map to guide the catheter (Fig. 35-10). The road map technique is often used during catheterization of a patient with a high-grade stenosis or an occlusion within a peripheral runoff vessel. Likewise, the intraarterial road map technique is also applied in *superselective catheterization* and as a monitor during arterial embolization.

### INTRAVENOUS DIGITAL SUBTRACTION ANGIOGRAPHY

Currently, IV DSA is performed infrequently. In patients with groin hematomas or possible cellulitis, an IV DSA is helpful in excluding a pseudoaneurysm or mycotic aneurysm of the artery. When the radiologist has difficulty catheterizing the artery, an IV DSA examination may be helpful in determining the anatomy of the vessel and in facilitating subsequent catheter placement.



**Fig. 35-9** Intraarterial DSA image of distal superficial femoral (F) and popliteal (P) arteries, showing diffuse, near occlusive disease (arrows).



**Fig. 35-10** Road map image of right external iliac artery during balloon angioplasty. The roadmap image was helpful in crossing the stenosis and correctly centering the angioplasty balloon at the stenosis (arrow).

### DIGITAL SPOT IMAGING

Digital imaging equipment can be used for many imaging situations in which the subtraction capabilities and rapid acquisition capabilities used for angiography are not necessary. The digital spot imaging equipment is well suited for most R/F applications, including gastrointestinal, genitourinary, myelographic, arthrographic, and even skeletal examinations. For example, Fig. 35-11 shows a barium study demonstrating the distal part of the stomach and the duodenum.

### Conclusion

DSA has had a great impact on diagnostic radiology. Its advantages over film angiography are a much greater contrast sensitivity, a lower cost, and the immediate availability of results. The digital nature of the data also permits quantitative analysis of DSA images; this has proved valuable, particularly in cardiac applications. The increased contrast sensitivity has permitted lower total volumes and concentrations of contrast media to be used. As a result, patients experience less discomfort, and toxicity is a less frequent problem.

The digital imaging system, originally developed for subtraction images, now has sufficient image quality for unsubtracted imaging applications. In the general R/F suite, unsubtracted digital images are of sufficient quality to replace traditional spot-film devices based on film-screen technology. In addition to excellent image quality, the ease of use and rapid display of images on a digital system are extremely advantageous. Images are available on the monitor immediately, eliminating the need to wait while film is processed or cassettes are changed. The digital nature of the image data also lends itself to electronic archiving and transmission of the images. Digital spot radiography is on the verge of becoming commonplace.

The author thanks John C. McDermott, M.D., of the University of Wisconsin at Madison, for his assistance in developing this chapter.



Fig. 35-11 Digital spot image from a barium study, demonstrating lower stomach (arrow) and duodenum (arrowhead).



## Definition of Terms

**acquisition rate** Rate, in images per second, that x-ray images are produced.

**angiography** Producing x-ray images of the blood vessels after injection of contrast medium.

**artifact** Any undesirable side effect resulting from an image-processing technique.

**digital** Information stored in discrete units, called *bits*, which are used to form a binary code for representing information.

**digital disk** Circular plate coated with magnetic material and used to store digital data.

**digital subtraction angiography (DSA)** Use of digitally recorded x-ray images to produce subtraction images of vessels.

**digitize** Process of converting a continuous analog voltage signal into a discrete digital value.

**edge enhancement** Making the edges of anatomic structures more clearly visualized through intentional unsharp masking and/or computer manipulation.

**frame** Single image from sequence of images.

**hard copy** Copy of video image printed on film.

**image intensifier** Imaging device that converts an x-ray distribution (image) to an optical image with a large increase in brightness.

**II/TV** Image intensifier/television unit.

**image processor** Special-purpose computer designed to operate on images in a short time.

**input phosphor** Material coated on the input surface of an image intensifier tube; emits light in response to the absorption of x-rays.

**landmarking** Process in which a reduced-contrast mask image is superimposed on a subtraction image so that the arteries can be seen in relation to the local anatomy. Without landmarking the arteries appear on a completely blank background.

**laser printer** Device that uses a scanning laser beam to produce a copy of images on film.

**mask** Image in which the arteries do not contain iodine; the image is subtracted from images with iodine in the arteries.

**matrix** Two-dimensional array of pixel values that make up an image.

**memory** Portion of an image processor in which the numbers that represent an image are stored.

**misregistration** Occurs when the two images used to form a subtraction image are slightly displaced from one another.

**multiformat camera** Device that produces copies of images on a single film.

**nonionic contrast medium** Contrast agent that does not ionize in solution and is safer, less painful, and better tolerated by the patient than ionic contrast medium.

**output phosphor** Material that is coated on the output surface of an image intensifier; emits light (an image) in response to being struck by electrons.

**picture archive and communication system (PACS)** System of computers linked together via a network to store and transmit digital images throughout the network. The network can be within a hospital institution but may also include remote sites.

**pixel (picture element)** One of the small cells an image breaks into when it is digitized; each cell represents only a small fraction of an entire picture.

**pixel shifting** Shifting of a digital image to compensate for misregistration marks caused by patient motion; an alternative to remasking.

**postprocessing** Image-processing operations performed when reviewing an imaging sequence.

**real time** Any image-processing technique that can be performed within a time frame that is so short as to appear instantaneous.

**remask** Repeating the masking process by choosing a different mask image to correct misregistration marks.

**road map technique** Image of the contrast-filled arteries is superimposed on the fluoroscopic image and acts as a road map to guide catheter placement.

**semiconductor** Solid-state material used in the construction of electronic devices such as transistors or integrated circuits.

**subtracted** When the mask image is used to remove the scout image (via electronic superimposition) from the postinjection angiographic image.

**superselective** When the catheter is advanced past the main arteries into smaller, more distal, branches.

**unsharp masking** Process in which a blurred copy of an image is subtracted from the original image to produce edge enhancement.

**unsubtracted image** Image that has not been subtracted from a mask image.

**video tape recorder** A device that uses magnetic tape to record video images.

**view trace** Process in which several images, with contrast in different parts of the arteries, are added together to produce one image with contrast in all parts of the arteries.

**zoom** Magnification of an image via interpolation or pixel duplication; resolving power remains unchanged.



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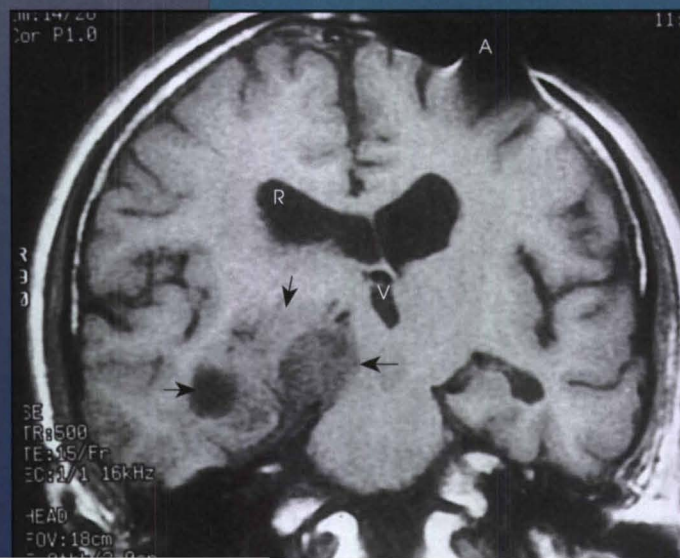


36

# MAGNETIC RESONANCE IMAGING

LUANN J. CULBRETH

Coronal MRI scan of the brain in a patient with a meningioma arising from the tentorium cerebelli. The precontrast T1-weighted image shows an inhomogeneous area of abnormality (*black arrows*), with mass effect elevating the right lateral ventricle (*R*) and midline shift of the third ventricle (*V*). Artifact (*A*) from metal in skull from previous surgery.



## OUTLINE

- Principles of magnetic resonance imaging, 386
- Comparison of magnetic resonance imaging and conventional radiography, 386
- Historical development, 386
- Physical principles, 387
- Equipment, 389
- Safety of magnetic resonance imaging, 392
- Examination protocols, 395
- Clinical applications, 402
- Spectroscopy, 412
- Conclusion, 413
- Definition of terms, 413

## Principles of Magnetic Resonance Imaging

*Magnetic resonance imaging (MRI)*\* has generated a great deal of interest among medical workers and the general public because it is an examination technique that provides both anatomic and physiologic information noninvasively. Like computed tomography (CT) (see Chapter 33), MRI is a computer-based cross-sectional imaging modality. However, the physical principles of MRI are totally different from those of CT and conventional radiography in that no x-rays are used to generate the MRI image. Indeed, no ionizing radiation of any kind is used in MRI. Instead, MRI creates images of structures through the interactions of magnetic fields and radio waves with tissues.

MRI was originally called *nuclear magnetic resonance (NMR)*. The word “nuclear,” indicating that the nonradioactive atomic nucleus played an important role in the technique, has since been dissociated from MRI because of public apprehension about nuclear energy and nuclear weapons—neither of which is associated with MRI in any way (unless by coincidence a nuclear power plant is supplying electricity to an MRI unit). In addition, some forms of MRI do not involve the atomic nucleus and may, in the future, be used for imaging under the “magnetic resonance” umbrella.

\*Almost all italicized words on the succeeding pages are defined at the end of this chapter.

## Comparison of Magnetic Resonance Imaging and Conventional Radiography

Because MRI provides sectional images, it serves as a useful adjunct to conventional x-ray techniques. On a radiograph, all body structures exposed to the x-ray beam are superimposed into one “flat” image. In many instances, multiple projections or contrast agents are required to clearly distinguish one anatomic structure or organ from another. Sectional imaging techniques such as ultrasonography, CT, and MRI more easily separate the various organs because there is no superimposition of structures. However, *multiple slices* (cross sections) are required to cover a single area of the body.

In addition to problems with overlapping structures, conventional radiography is relatively limited in its ability to distinguish types of tissue. In radiographic techniques, *contrast* (the ability to discriminate two different substances) depends on differences in x-ray *attenuation* within the object and the ability of the recording medium (e.g., film) to detect these differences.

Radiographs cannot detect small attenuation changes. In general, conventional radiographs can distinguish only air, fat, soft tissue, bone, and metal because of the considerable difference in attenuation with each group. Most organs, such as the liver and kidneys, cannot be separated by differences in x-ray attenuation alone unless the differences are magnified through the use of contrast agents.

CT is much more sensitive to small changes in x-ray attenuation than is plain-film radiography. Thus CT can distinguish the liver from the kidneys on the basis of their different x-ray attenuation, as well as by position.

Like CT, MRI can resolve relatively small contrast differences among tissues. It should be emphasized, however, that these tissue differences are unlike the differences in x-ray attenuation and the exiting radiation that produces the image. Contrast in MRI depends on the interaction of matter with electromagnetic forces other than x-rays.

## Historical Development

The basic principle of MRI (discussed more fully in the next section) is that protons in certain atomic nuclei, if placed in a magnetic field, can be stimulated by (absorb energy from) radio waves of the correct frequency. After this stimulation the protons relax while energy is induced into a receiver antenna (the MRI signal), which is then digitized into a viewable image. *Relaxation times* represent the rates of signal decay and the return of protons to equilibrium.

Separate research groups headed by Bloch and Purcell first discovered the properties of magnetic resonance in the 1940s. Their work led to the use of MRI *spectroscopy* for the analysis of complex molecular structures and dynamic chemical processes. In 1952 Bloch and Purcell were jointly awarded the Nobel Prize in physics, and spectroscopic MRI is still in use today.

Nearly 20 years after the properties of MRI were discovered, Damadian showed that the relaxation time of water in a tumor differed from the relaxation time of water in normal tissue. This finding suggested that images of the body might be obtained by producing maps of relaxation rates. In 1973 Lauterbur published the first cross-sectional images of objects obtained with MRI techniques. These first images were crude, and only large objects could be distinguished. Since that time, MRI technology has developed so much that tiny structures can be imaged rapidly with increased resolution and contrast.



## Physical Principles

### SIGNAL PRODUCTION

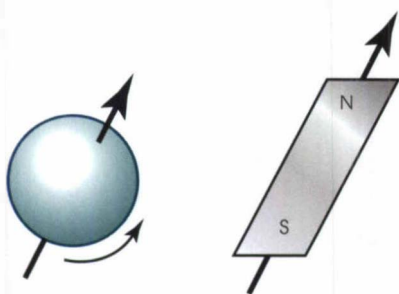
The structure of an atom is often compared to that of the solar system, with the sun representing the central atomic *nucleus*. The planets orbiting the sun represent the electrons circling around the *nucleus*. MRI depends on the properties of the nucleus. Currently, most MRI scanners use the element hydrogen, the nucleus of which is a single proton, to generate a *signal*. Hydrogen nuclei are the strongest nuclear magnets on a per-nucleus basis; thus they create the strongest MRI signal. Also, hydrogen is the most common element in the body, which is another reason that it creates the strongest signal. Strong signals are important to produce satisfactory images.

Many, but not all, atomic nuclei have magnetic properties, which means they act like tiny bar magnets (Fig. 36-1). Normally the magnetic protons point in random directions in the human body, as shown in Fig. 36-2. However, if the body is placed in a strong, uniform magnetic field, the nuclei attempt to line up with the direction of the magnetic field, much as iron filings line up with the field of a toy magnet. The word *attempt* is appropriate because the protons do not line up precisely with the external field but at an angle to the field, and they rotate about the direction of the magnetic field in a manner similar to the wobbling of a spinning top. This wobbling motion, depicted in Fig. 36-3, is called *precession* and occurs at a specific *frequency* (rate) for a given atom's nucleus in a magnetic field of a specific strength. These precessing protons can absorb energy if they are exposed to *radiofrequency (RF)* pulses, which are very fast bursts of radio waves, provided that the radio waves and nuclear precession are of the same frequency. This absorption of energy occurs through the process of *resonance*.

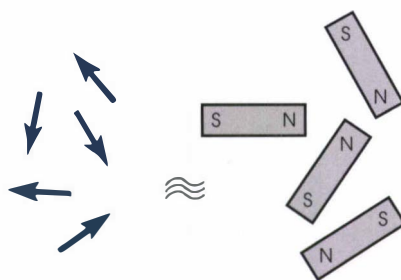
The resonant frequency varies depending on the field strength of the MRI scanner. For example, at a field strength of 1.5 *tesla* the frequency is approximately 63 MHz; at 1 *tesla*, the frequency is approximately 42 MHz; at 0.5 *tesla*, the frequency is approximately 21 MHz; and at 0.2 *tesla*, the frequency is approximately 8 MHz.

Before exposure to the RF pulse, the bulk of the hydrogen protons are oriented with the direction of the magnetic field. This causes the tissues to be magnetized in the longitudinal direction, which is also parallel to the magnetic field. When the RF pulse is applied and the protons absorb the energy, the result is a reorientation of the bulk of the tissue magnetization into a plane perpendicular to the main field. This is known as the *transverse plane*. The magnetization in the transverse plane also precesses at the same resonant frequency. The precessing transverse magnetization in the tissues then creates an electrical current in the receiving *antenna*. This follows Faraday's law of induction, in which a moving magnetic field induces electrical current in a coil of wire. The electrical current in this application is measured as the MRI signal, which is much like the broadcasting radio waves that induce current in a car radio antenna.

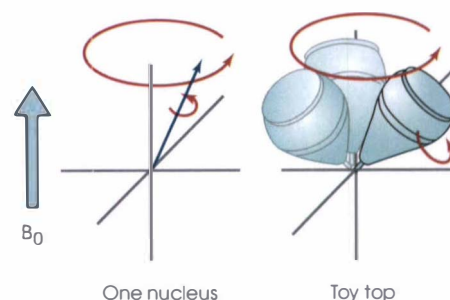
The MRI signal is picked up by a sensitive antenna, amplified, and processed by a computer to produce a sectional image of the body. This image, like the image produced by a CT scanner, is an electronic image that can be viewed on a television monitor and adjusted to produce the most information. If desired, the image can be photographed for further study.



**Fig. 36-1** A proton with magnetic properties can be compared to a tiny bar magnet. The curved arrow indicates that a proton spins on its own axis; this motion is different from that of precession.



**Fig. 36-2** In the absence of a strong magnetic field, the protons (arrows) point in random directions and cannot be used for imaging.



**Fig. 36-3** Precession. Both the protons (arrow) and the toy top spin on their own axes. Both also rotate (curved arrows) around the direction of an external force in a wobbling motion called precession. Precessing protons can absorb energy through resonance.  $B_0$  represents the external magnetic field acting on the nucleus. The toy top precesses under the influence of gravity.

Many other nuclei in the body are potential candidates for use in imaging. Nuclei from elements such as phosphorus and sodium may provide more useful or diagnostic information than hydrogen nuclei, particularly in efforts to understand the metabolism of normal and abnormal tissues. Metabolic changes may prove to be more sensitive and specific in detecting abnormalities than the more physical and structural changes recognized by hydrogen-imaging MRI or by CT. However, the MRI signal from nonhydrogen nuclei is weak, imaging requires more elaborate equipment, and to date anatomic detail produced with sodium and phosphorus MRI is less complete than that produced with hydrogen MRI. Nonhydrogen nuclei may be of particular importance for combined imaging and spectroscopy, in which small volumes of tissue may be analyzed for chemical content.

### SIGNIFICANCE OF THE SIGNAL

Conventional radiographic techniques, including CT, produce images based on a single property of tissue: x-ray attenuation or density. MRI images are more complex because they contain information about three properties of tissue: nuclear density, relaxation rates, and flow phenomena. Each property contributes to the overall strength of the MRI signal. Computer processing converts signal strength to a shade of gray on the image. Strong signals are represented by white in the image, and weak signals are represented by black.

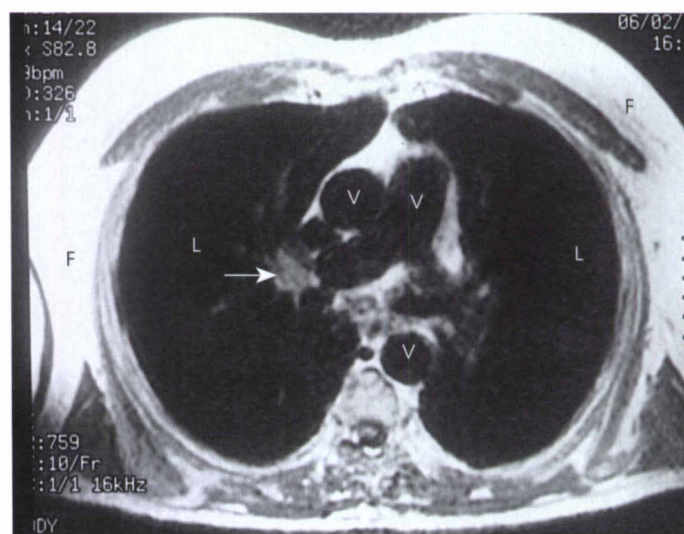
One determinant of signal strength is the number of precessing nuclei (spin density) in a given volume of tissue. The signal produced by the excited nuclei is proportional to the number of nuclei present. Therefore signal strength depends on the nuclear concentration, or density. Because the hydrogen nucleus is a single proton, its nuclear concentration is often referred to as *proton density*. Most soft tissues, including fat, have a similar number of protons per unit volume; therefore the use of proton density characteristics alone poorly separates most tissues. However, some tissues have few hydrogen nuclei per unit of volume; examples include the cortex of bone and air in the lungs. These have a weak signal as a result of low proton density and can be easily distinguished from other tissues.

MRI signal intensity also depends on the relaxation times of the nuclei. One component of *relaxation* is the release of energy by the excited protons, which occurs at different rates in different tissues. Excited nuclei relax through two processes. The process of nuclei releasing their excess energy to the general environment or lattice (the arrangement of atoms in a substance) is called *spin-lattice relaxation*. The rate of this relaxation process is measured in milliseconds and is labeled as T1. *Spin-spin relaxation* is the release of energy by excited nuclei through interaction among themselves. The rate of this process is also measured in milliseconds but is labeled as T2.

The rates of relaxation (T1 and T2) of a hydrogen nucleus depend on the chemical environment in which the nucleus is located. Chemical environment differs among tissues. For example, the chemical environment of a hydrogen nucleus in the spleen differs from that of a hydrogen nucleus in the liver. Therefore the relaxation rates of these nuclei differ, and the MRI signals created by these nuclei differ. The different relaxation rates in the liver and spleen result in different signal intensities and appearances on the image, enabling the viewer to discriminate between the two organs. Similarly, fat can be separated from muscle and many tissues can be distinguished from others, based on the relaxation rates of their nuclei. Indeed, the most important factor in tissue discrimination is the relaxation time.

The signals produced by MRI techniques contain a combination of proton density and T1 and T2 information. However, it is possible to obtain images weighted toward any one of these three parameters by stimulating the nuclei with certain specific radio-wave *pulse sequences*. In most imaging sequences a short T1 (fast spin-lattice relaxation rate) produces a high MRI signal on T1-weighted images. Conversely, a long T2 (slow spin-spin relaxation rate) generates a high signal on T2-weighted images.

The final property that influences image appearance is flow. For complex physical reasons, moving substances usually have weak MRI signals. (With some specialized pulse sequences, the reverse may be true; see the discussion of magnetic resonance angiography [MRA] later in the chapter.) With standard pulse sequences, flowing blood in vessels produces a low signal and thus is easily discriminated from surrounding stationary tissues without the need for the contrast agents required by regular radiographic techniques. Stagnant blood, such as an acute blood clot, typically has a high MRI signal in most imaging schemes as a result of its short T1 and long T2. The flow sequences of MRI may facilitate the assessment of vessel patency or the determination of the rate of blood flow through vessels (Fig. 36-4).



**Fig. 36-4** Axial 1.5-tesla T1-weighted MRI scan through the upper chest. Lungs (L) have low signal as a result of low proton density. Fat (F) has high signal because of its short T1 relaxation rate. Moving blood in vessels (V) has low signal from the flow phenomenon. Hilar tumor (arrow) is easily identified, outlined against the low signal intensity of the lung and the vessels.



## Equipment

Like CT, MRI requires a patient area (magnet room), a computer room, and an operator's console. A separate diagnostic workstation is optional.

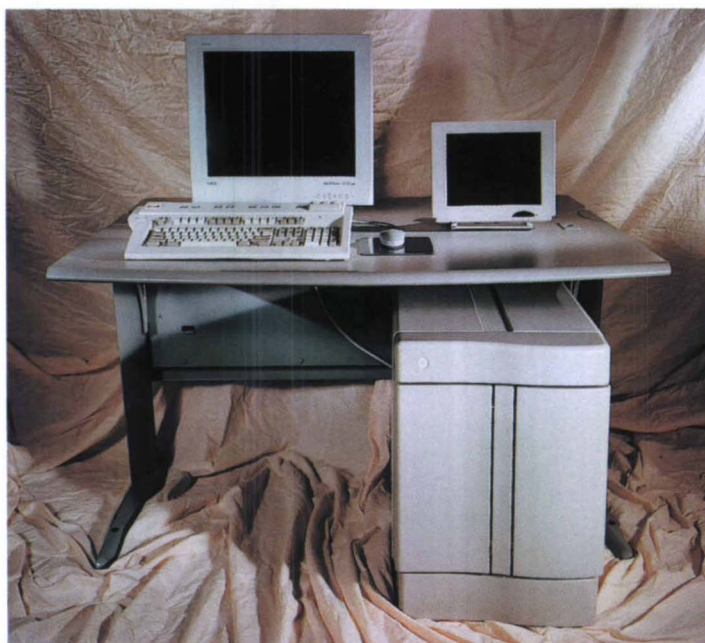
### CONSOLE

The operator's console is used to control the computer. The computer initiates the appropriate radio-wave transmissions and then receives and analyzes the data. Images are viewed on the operator's console to ensure that the proper part of the patient is being evaluated (Fig. 36-5). Images may be printed, most often on special medical film using a laser or multiimage camera.

The independent diagnostic workstation may be used to perform the same functions as those of the operator's console, depending on system configuration. However, usually only the operator's console can control the actual imaging process.

### COMPUTER ROOM

The computer room houses the electronics necessary for transmitting the radio-wave pulse sequences and for receiving and analyzing the MRI signal. The *raw data* and the computer-constructed images can be stored on a computer disk temporarily but are usually transferred to a magnetic tape or an optical disk for permanent storage and retrieval.



**Fig. 36-5** Operator's console. This device controls the imaging process and allows visualization of images.

(Courtesy General Electric Medical Systems, Milwaukee, W.I.)



## MAGNET ROOM

The magnet is the major component of the MRI system in the scanning room. This magnet must be large enough to surround the patient and any antennas that are required for radio-wave transmission and reception. Antennas are typically wound in the shape of a positioning device for a particular body part. These are commonly referred to as *coils*. The patient is usually placed within the coil. Surface coils are placed directly on the patient and are used in the imaging of superficial structures. However, the patient and coil must still be within the magnet to be exposed to the proper magnetic field for imaging. The patient lies on the table and is advanced into the imaging magnetic field (Fig. 36-6).

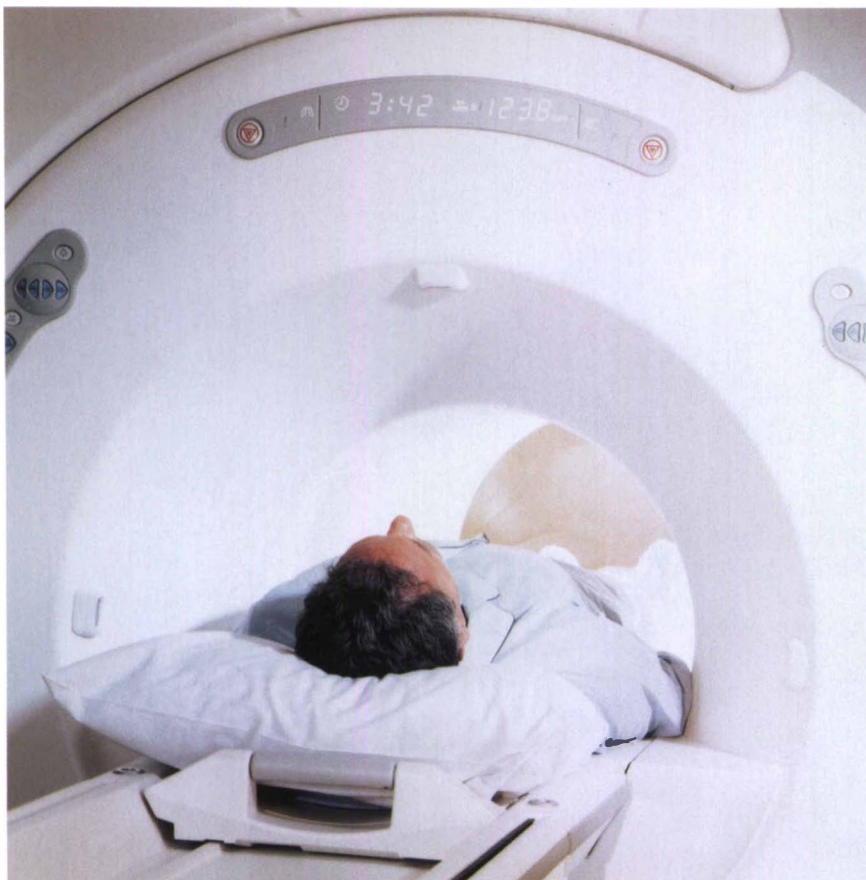


Fig. 36-6 Patient prepared for MRI.

(Courtesy General Electric Medical Systems, Milwaukee, WI.)

Various magnet types and strengths may be used to provide the strong uniform magnetic field required for imaging.

*Resistive magnets* are simple but large electromagnets consisting of coils of wire.

A magnetic field is produced by passing an electric current through the wire coils. High magnetic fields are produced by passing a large amount of current through a large number of coils. The electrical resistance of the wire produces heat and limits the maximum magnetic field strength of resistive magnets. The heat produced is conducted away from the magnet by a cooling system.

*Superconductive (cryogenic) magnets* are also electromagnets. However, their wire loops are cooled to very low temperatures with liquid helium to reduce electrical resistance. This permits higher magnetic field strengths than those produced by resistive magnets.

*Permanent magnets* are a third source for producing the magnetic field. A permanent magnet has a constant field that does not require additional electricity or cooling. The early permanent magnets were extremely heavy, even when compared to the massive superconductive and resistive units. Because of their weight, these magnets were difficult to place for clinical use. With improvements in technology, permanent magnets have become more competitive with the other magnet types. For example, the magnetic field of permanent magnets does not extend as far away from the magnet (*fringe field*) as do the magnetic fields of other types of magnets. Fringe fields are a problem because of their effect on nearby electronic equipment.

Various MRI systems operate at different magnetic field strengths. The choice of optimum field strength for imaging is controversial. Magnetic field strength is measured in tesla or *gauss* (G). Most MRI has been performed with field strengths ranging from 0.2 to 1.5 tesla. Resistive systems generally do not exceed 0.15 tesla, and permanent magnet systems do not exceed 0.3 tesla. Higher field strengths require superconductive technology. However, the U.S. Food and Drug Administration currently limits clinical MRI systems to a maximum field strength of up to 3 tesla. Most research has concluded that field strengths in this range do not produce any substantial harmful effects.

Regardless of magnet type, MRI units remain relatively difficult to install in hospitals. Current units are quite heavy—up to 10 tons for resistive and superconductive magnets and approximately 100 tons for some permanent magnets. Some institutional structures cannot support these weights without reinforcement. In addition, choosing a location for an MRI unit can be difficult because of fringe fields. With resistive and superconductive magnets, the fringe field extends in all directions and thus may interfere with nearby electronic or computer equipment, such as television monitors and computer tapes. In addition, metal objects moving near the magnetic fringe field, such as automobiles or elevators, may cause ripples in the field, similar to the ripples caused by a pebble thrown into a pond. These ripples can be carried into the center of the magnet, where they distort the field and ruin the images. Thus MRI sites must be located far enough away from moving metal objects. Efforts continue to be made to find more ways to shield the magnetic fringe field to prevent its extension beyond the patient area.

Stray radio waves present another difficulty in the placement of MRI units. The radio waves used in MRI may be the same as those used for other nearby radio applications. Stray radio waves can be picked up by the MRI antenna coils and interfere with normal image production. Many MRI facilities require specially constructed rooms to shield the antenna from outside radio interference, thus adding to the cost of the installation.

## Safety of Magnetic Resonance Imaging

MRI is generally considered safe. It is often preferred over CT for the imaging of children because it does not use ionizing radiation, which has known potential adverse health effects. The young and growing child's body is thought to be more susceptible to the effects of ionizing radiation. Nevertheless, a number of potential safety issues concerning MRI must be raised, some related to potential direct effects on the patient from the imaging environment, and others related to indirect hazards.

Opinions differ about the safety of the varying magnetic and RF fields to which the patient is directly exposed. Many studies in which experimental animal and cell culture systems were exposed to these fields over long periods have reported no adverse effects, whereas others have reported changes in cell cultures and embryos. Some energy is deposited in the patient during imaging and is dissipated in the body as heat. The resulting changes appear to be less than the levels considered clinically significant, even in areas of the body with poor heat dissipation such as the lens of the eye. The significance of direct short-term exposure (i.e., exposure of a patient) and long-term exposure (i.e., exposure of an employee who works with MRI) is not clear. No clear association of MRI with adverse effects in humans has been proven, but research is continuing.

A number of hazards related to MRI have, however, been well documented. Objects containing magnetic metals (e.g., iron, nickel, cobalt) in various combinations may be attracted to the imaging magnet with sufficient force to injure patients or personnel who may be interposed between them. Scissors, oxygen tanks, and patient gurneys are among the many items that have been drawn into the magnetic field at MRI sites. Metallic implants within patients or personnel can become dislodged within the body and cause injury if they are in delicate locations.

Examples include intracranial aneurysm clips, auditory implants, and metallic foreign bodies in the eye. On the other hand, long-standing, firmly bound surgical clips, such as those from a cholecystectomy, do not pose problems. Electronic equipment can malfunction when exposed to strong magnetic fields. The most critical items in this category are cardiac pacemakers and the similar automatic implantable cardiac defibrillators. Therefore patients, visitors, and personnel should be screened to ensure that they do not have metallic objects on or in their bodies that could be adversely affected by exposure to strong magnetic fields.

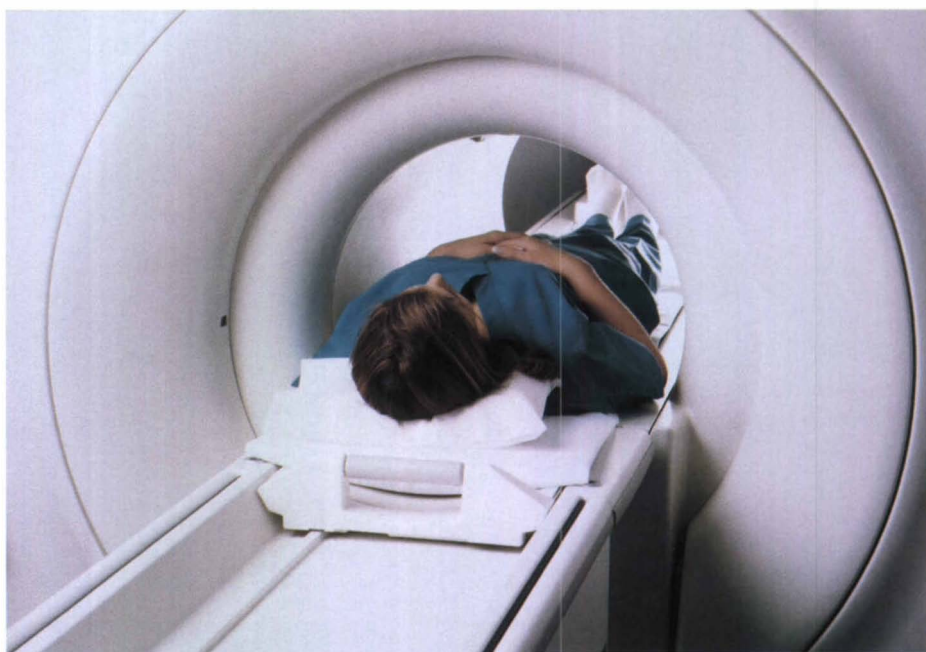
Patients have received local burns from wires, such as electrocardiographic (ECG or EKG) leads, and other monitoring devices touching their skin during MRI examinations. These injuries have resulted from electrical burns caused by currents induced in the wires or thermal burns caused by heating of the wires. Such burns can be prevented by checking wires for frayed insulation, ensuring that no wire loops are within the magnetic field, and placing additional insulation between the patient and any wires exiting the MRI system.

The varying magnetic forces in an MRI unit act on the machine itself, causing knocking or banging sounds. These noises can be loud enough to produce temporary or permanent hearing damage. The use of earplugs or nonmagnetic headphones can be helpful in preventing auditory complications and are highly recommended to be used by each patient being scanned.



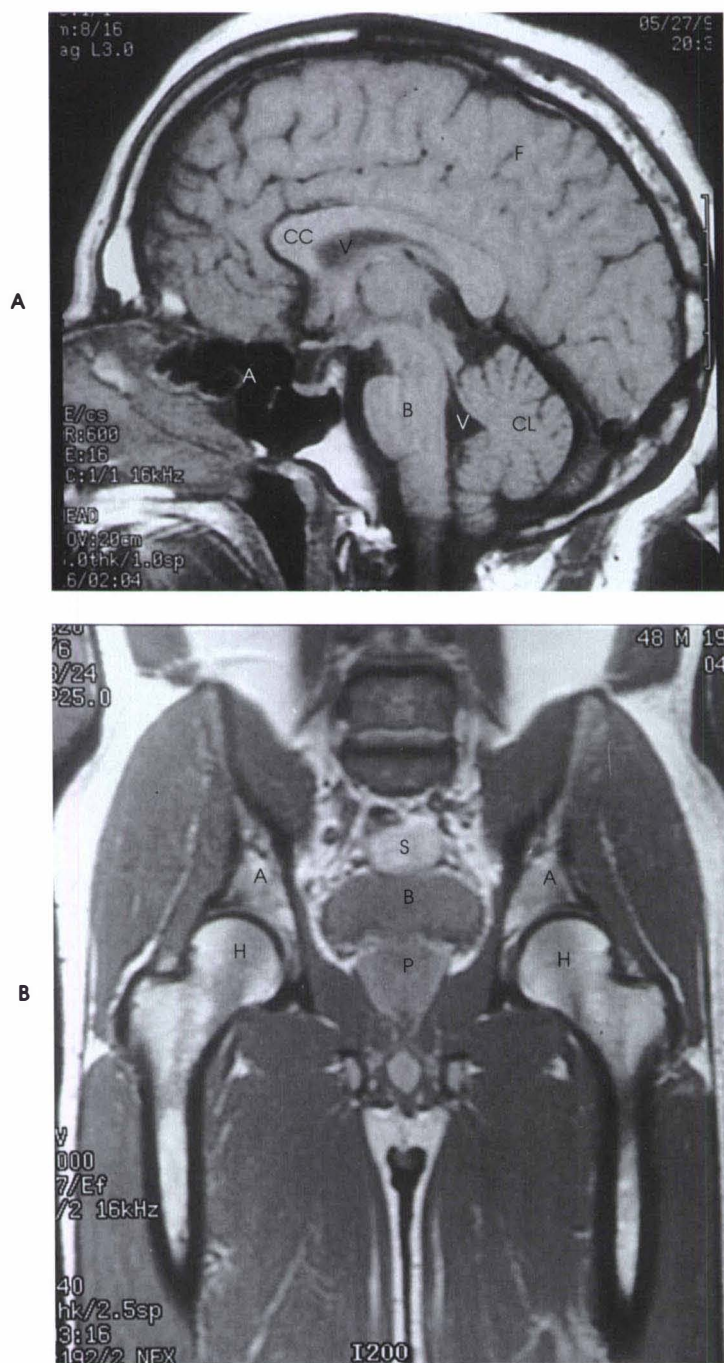
Claustrophobia can be a significant impediment to MRI in up to 10% of patients (Fig. 36-7). Patient education is perhaps most important in preventing this problem, but tranquilizers, appropriate lighting and air movement within the magnet bore, and mirrors or prisms that enable a patient to look out of the imager may be helpful. Claustrophobia can also be prevented by having a family member or friend accompany the patient and be present in the room during the scan.

In superconductive magnet systems, rapid venting of the supercooled liquid gases (helium) from the magnet or its storage containers into the surrounding room space is a rare but potential hazard because the relative concentration of oxygen in the air could be reduced to unsafe levels. Unconsciousness or asphyxiation could result. Oxygen monitoring devices in the magnet or cryogen storage room can signal personnel when the oxygen concentration falls too low. Personnel may then evacuate the area and activate ventilation systems to exchange the escaped gas for fresh air.



**Fig. 36-7** Patient inside a superconducting 1.5-tesla magnet. Some patients cannot be scanned because of claustrophobia.

(Courtesy General Electric Medical Systems, Milwaukee, W.I.)



**Fig. 36-8** Two images (different patients) from a 1.5-tesla superconductive MRI scanner, showing excellent resolution of images. **A**, This image shows remarkable anatomic detail in a midsagittal image of the head. Normal folds (*F*) on the inner surface of the brain are identified. *CC*, Corpus callosum; *CL*, cerebellum; *B*, brainstem; *V*, ventricle; *A*, air in sinuses. **B**, This coronal image of the pelvis shows anatomic relationships of the prostate (*P*), which is enlarged and elevating the bladder (*B*). Hips (*H*) and acetabula (*A*) are also shown. A loop of the sigmoid (*S*) colon is on top of the bladder. This degree of resolution in coronal or sagittal images would be difficult to obtain by reformatting a series of transverse CT slices.

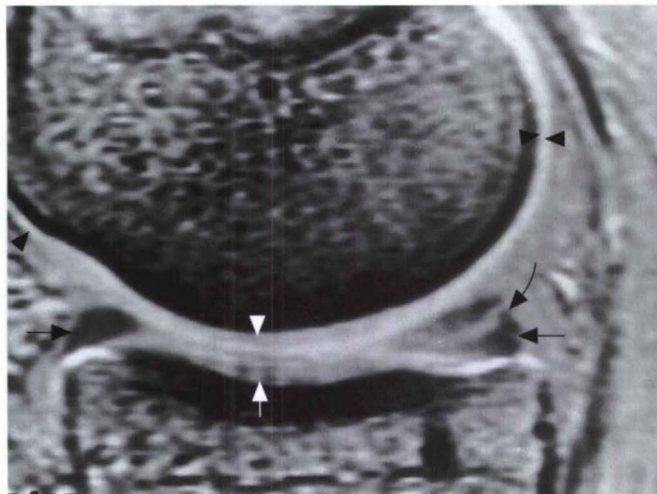
## Examination Protocols

### IMAGING PARAMETERS

The availability of many adjustable parameters makes MRI a complex imaging technique. Knowledge of the patient's clinical condition or probable disease is important in choosing the proper technique and in imaging the correct area of the body.

The operator may choose to obtain MRI images in sagittal, coronal, transverse, or oblique planes. These are independently acquired images with equal resolution in any plane (Fig. 36-8). In contrast, data can be obtained only in the transverse plane with CT. Sagittal and coronal CT images can then be generated by reformatting the data from a series of transverse slices, usually with a loss of resolution.

Another MRI technique, especially when a large number of thin slices and/or multiple imaging planes are desired, is three-dimensional imaging. In this technique, MRI data are collected simultaneously from a three-dimensional block of tissue rather than from a series of slices. Special data collection techniques and subsequent computer analysis allow the images from the single imaging sequence to be displayed in any plane (Fig. 36-9).

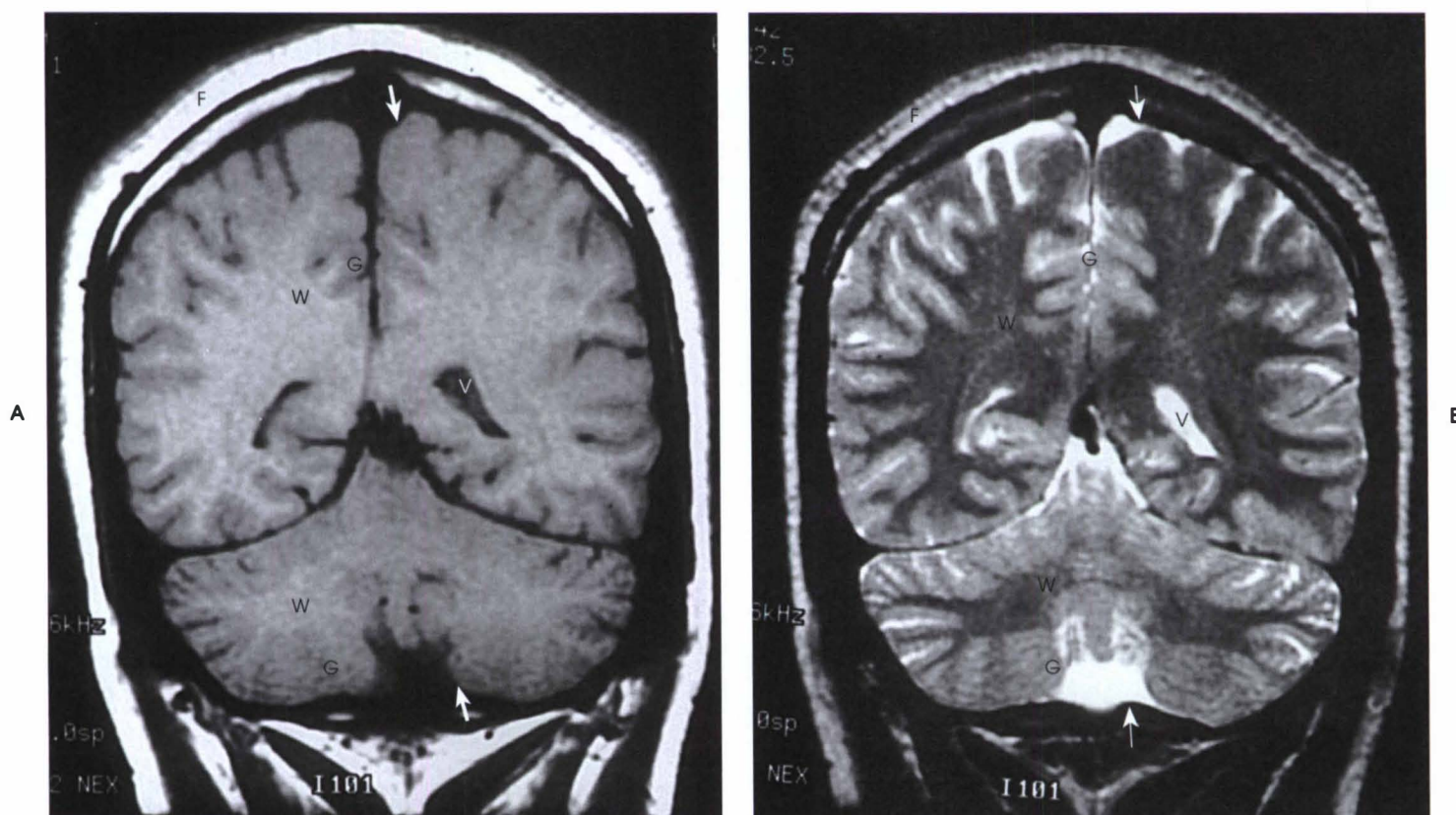


**Fig. 36-9** Single slice from a three-dimensional acquisition of the knee on a 1.5-tesla MRI unit. Data from an entire volume within the imaging coil are obtained concurrently. The data may then be reconstructed into thin slices in any plane, such as the sagittal image shown here. This imaging sequence shows hyaline cartilage (*arrowheads*) as a fairly high signal intensity rim overlying the bone. Meniscal fibrocartilage (*arrows*) has low signal intensity. High signal intensity from joint fluid in a tear (*curved arrow*) within the posterior meniscus is visualized.



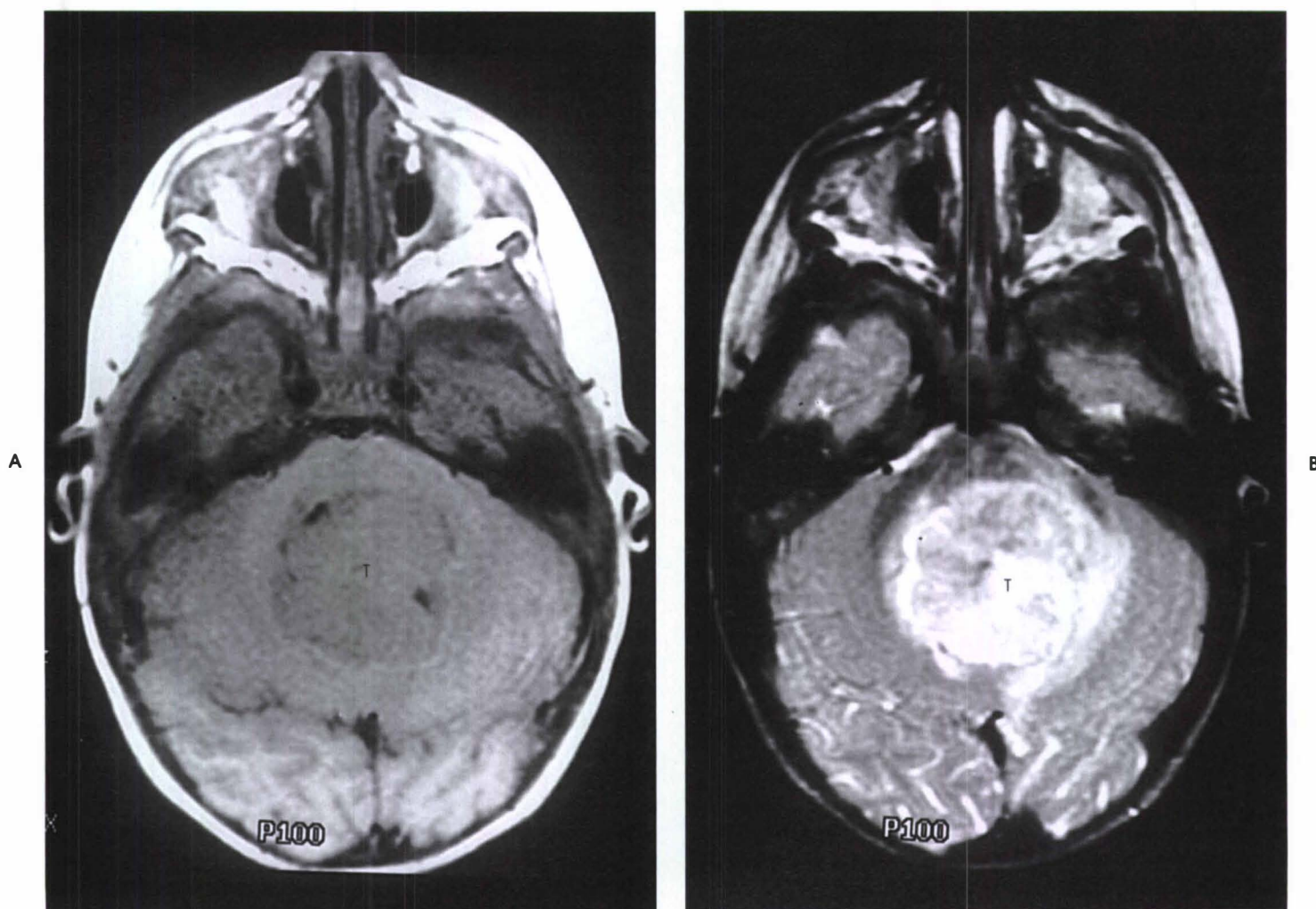
Slice thickness is important in the visualization of pathology. More MRI signal is available from a thicker slice than a thinner slice, so thicker slices may provide images that are less grainy. However, small pathologic lesions may be hidden by the surrounding tissues in the thicker slices. Therefore slice thickness may need to be adjusted based on the type of lesion under investigation.

Another important MRI parameter is overall imaging time. As imaging time (per slice) is lengthened, more MRI signal is available for analysis. Image quality thus improves with increased signal. However, fewer patients can be imaged when extended data acquisitions are performed. In addition, patient motion increases with prolonged imaging times; as a result, image quality is reduced.



**Fig. 36-10** Coronal 1.5-tesla images through a normal brain. **A**, The T1-weighted image shows relatively low differentiation of gray matter (G) and white matter (W) within the brain. **B**, The heavily T2-weighted image shows improved differentiation between gray and white matter. Cerebrospinal fluid (CSF) around the brain (arrows) and within the ventricles (V) also changes in appearance with change in pulse sequence (low signal on T1-weighted image); fat (F) normally shows high signal intensity, whereas on the T2-weighted image, the signal intensity of fat is less than that of CSF.

The imaging sequence is a crucial parameter in MRI. Depending on the choice of pulse sequence, the resulting images may be more strongly weighted toward proton density, T1, or T2 information. Depending on the relative emphasis given to these factors, normal anatomy (Fig. 36-10) or a pathologic lesion (Fig. 36-11) may be easily recognized or difficult to see. It is not unusual for a lesion to stand out dramatically when one pulse sequence is used, yet be nearly invisible (same MRI signal as surrounding normal tissue) with a different pulse sequence. Considerable research continues to determine the optimum pulse sequences for scanning various patient problems.



**Fig. 36-11** Axial MRI scans using two different pulse sequences in a child with a medulloblastoma. **A**, The T1-weighted image shows limited contrast exists between the tumor (T) and normal brain. **B**, The lesion becomes dramatically more obvious using the pulse sequence of the T2-weighted image. Choice of pulse sequence is critical. These images also demonstrate how the lack of bone artifact makes MRI superior to CT for the imaging of posterior fossa lesions.

Although varying the timing parameters of an individual pulse sequence can alter the relative weighting of information received, certain classes of pulse sequences tend to emphasize information about proton density, T1, T2, and even flow. *Spin echo* sequences are the classic imaging sequences usually used with timing parameters to yield T1-weighted images, but they can also provide proton density-weighted images and T2-weighted images. *Inversion recovery* is a sequence that accentuates T1 information but can also provide a special result in that the timing parameters can be chosen to minimize signal intensity in a particular tissue. Fat is usually the tissue chosen to have its intensity minimized, and so-called *fat-suppressed images* can be useful when the high signal from extensive fat overwhelms small signal intensity differences in the tissues of interest. However, techniques to suppress the signal from fat have been developed for pulse sequences other than inversion recovery, and these newer techniques have generally replaced inversion recovery sequences for this purpose.

Standard imaging sequences such as spin echo and inversion recovery are relatively time consuming and slow patient “throughput,” or productivity regarding the number of procedures per unit of time. Therefore MRI engineers and physicists have developed faster pulse sequences to speed up examinations. The oldest and most common type of faster imaging sequence is the *gradient echo* pulse sequence. In the early 1990s a fast spin-echo pulse sequence, known as *rapid acquisition recalled echo*, was created. In recent years an even faster sequence, called *echo planar imaging*, has been implemented. Some imaging sequences are short enough that imaging can be accomplished during a breath hold. Many of the fast pulse sequences are sensitive to flow and may be used to provide images of blood vessels. (See the discussion of MRA later in this chapter.)

## POSITIONING

Patient positioning for MRI is usually straightforward. In general, the patient lies supine on a table that is subsequently advanced into the magnetic field. As previously discussed, it is important to ensure that the patient has no contraindications to MRI, such as a cardiac pacemaker or intracranial aneurysm clips. As previously noted, claustrophobia may be a problem for some patients because the imaging area is tunnel shaped in most MRI system configurations (see Fig. 36-7).



## COILS

The body part to be examined determines the shape of the antenna coil that is used for imaging (Fig. 36-12). Most coils are round or oval in shape, and the body part to be examined is inserted into the coil's open center. Some coils, rather than encircling the body part, are placed directly on the patient over the area of interest. These surface coils are best for the imaging of thin body parts, such as the limbs, or superficial portions of a larger body structure, such as the orbit within the head or the spine within the torso. Another form of surface coil is the endocavitary coil, which is designed to fit within a body cavity such as the rectum. This enables a receiver coil to be placed close to some internal organs that may be distant from surface coils applied to the exterior body. Endocavitary coils also may be used to image the wall of the cavity itself (Fig. 36-13).

## PATIENT MONITORING

Although most MRI sites are constructed so that the operator can see the patient during imaging, the visibility is often limited; thus the patient is relatively isolated within the MRI room (see Fig. 36-7). At most sites, intercoms are used for verbal communication with the patient, and some units have "panic buttons" with which the patient may summon assistance. However, these devices may be insufficient to monitor the health status of a sedated, anesthetized, or unresponsive patient. MRI-compatible devices now exist to monitor multiple physiologic parameters such as heart rate, respiratory rate, blood pressure, and oxygen concentration in the blood. Typically, leads from probes placed on extend to the operator's room, where the data are displayed on a monitor (see Fig. 36-6). Local policy and patient condition dictate which physiologic parameters are monitored.



**Fig. 36-12** A neurovascular coil used for imaging the brain and neck, including the blood vessels as seen in Figures 36-27 and 36-28.

(Courtesy General Electric Medical Systems.)



**Fig. 36-13** Axial image of the prostate obtained with an endorectal coil. The mixed signal intensity in the inner gland region (*I*) of the prostate results from benign prostatic hyperplasia. The high-intensity outer gland (*O*) is interrupted by a low intensity region representing prostatic carcinoma (*T*). The close proximity of the endorectal coil to the area of the desired imaging improves resolution. *V*, Signal void from rectum (coil itself is not imaged); *W*, rectal wall.

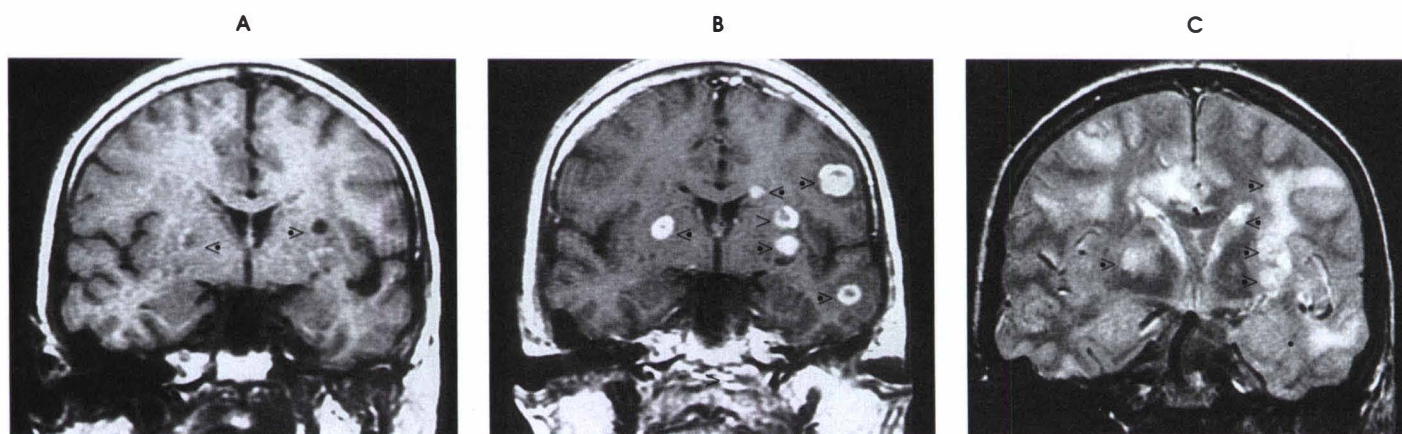
## CONTRAST MEDIA

Contrast agents that widen the signal differences in MRI images between various normal and abnormal structures are the subjects of a continuing research and development. A good orally administered agent for identifying bowel loops in MRI scans has not yet been identified. In CT scanning, the use of high-attenuation orally administered contrast medium allows clear differentiation of the bowel from surrounding lower-attenuation structures. However, in MRI scans, the bowel may lie adjacent to normal or pathologic structures of low, medium, and high signal intensity and these intensities may change as images of varying T1 and T2 weighting are obtained. It is difficult to develop an agent that provides good contrast between the bowel and all other structures under these circumstances. Air, water, fatty liquids (e.g., mineral oil), dilute iron solutions (e.g., Geritol), gadolinium compounds designed for IV use, barium sulfate, kaolin (a clay), and a variety of miscellaneous agents have all been used—none with complete success.

At this time the only IV MRI contrast agents approved in the United States for routine clinical use in the whole body are gadolinium-containing compounds. Gadolinium is a metal with *paramagnetic* effects. Pharmacologically, an intravenously administered gadolinium compound acts in a manner similar to radiographic iodinated IV agents: it distributes through the vascular system, its major route of excretion is the urine, and it respects the blood-brain barrier (i.e., it does not leak out from the blood vessels into the brain substance unless the barrier has been damaged by a pathologic process). Gadolinium compounds have lower toxicity and fewer side effects than the IV iodinated contrast media used in radiography and CT.

Gadolinium compounds are used most commonly in evaluation of the central nervous system (CNS). The most important clinical action of gadolinium compounds is the shortening of T1. In T1-weighted images, this provides a high-signal, high-contrast focus in areas where gadolinium has accumulated by leaking through the broken blood-brain barrier into the brain substance (Fig. 36-14). Furthermore, in gadolinium-enhanced T1-weighted images, brain tumors or metastases are better distinguished from their surrounding edema than in routine T2-weighted images. Gadolinium improves the visualization of small tumors or tumors that have a signal intensity similar to that of a normal brain, such as meningiomas. IV injections of gadolinium also have been used in dynamic imaging studies of body organs such as the liver and kidneys, similar to techniques using standard radiographic iodinated agents in CT.

A number of novel contrast agents for MRI are under development, but many of them are not yet approved for routine clinical use. A new manganese-based paramagnetic liver contrast agent (Teslascan) is now available. This IV-administered agent is used in the detection, characterization, localization, and evaluation of lesions of the liver. An iron oxide mixture (Feridex) is the only *superparamagnetic* contrast agent currently available. This contrast agent is also used to detect and diagnose liver lesions.



**Fig. 36-14** Use of IV-administered gadolinium contrast medium for lesion enhancement in coronal images of the brain. **A**, T1-weighted sequence. Two brain metastases (arrowheads) are identified as focal areas of low signal. **B**, Image obtained using similar parameters after IV administration of gadolinium contrast material. Previously seen metastases are more conspicuous, and additional metastases are visualized. **C**, T2-weighted image. High signal areas (arrowheads) represent metastases and surrounding edema; focal lesion size and precise location are more difficult to identify. Additional high signal intensity areas on T2-weighted image represent edema from focal lesions seen on other slices in the gadolinium-enhanced series.

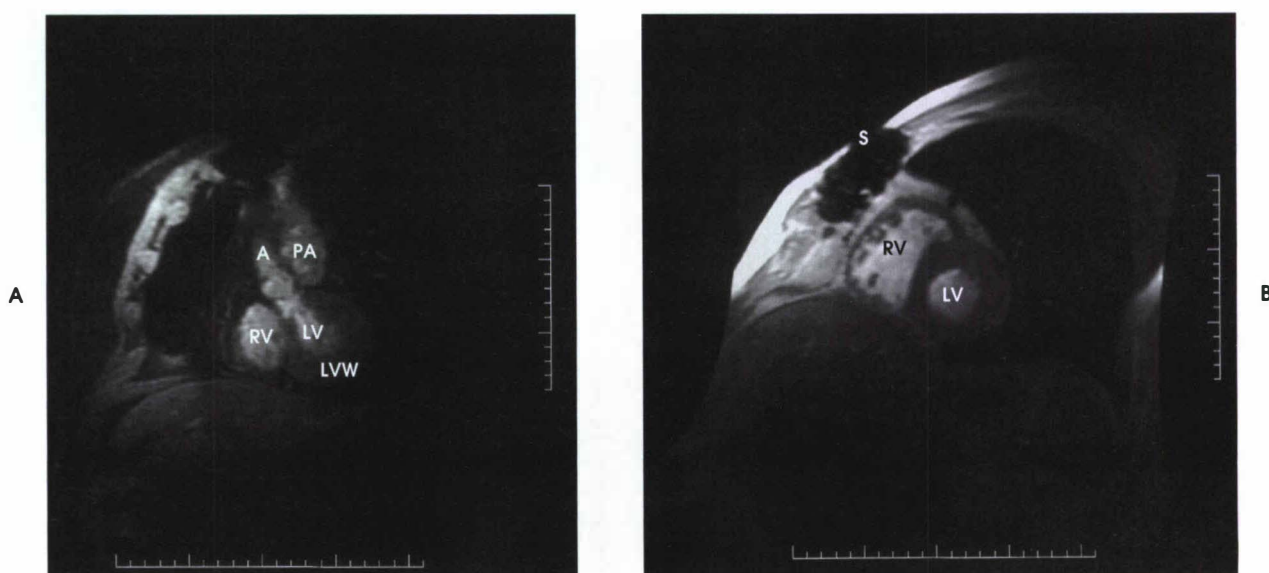


Contrast media currently in development include agents that are specifically designed to enhance the blood. Imaging using these agents may allow estimates of tissue perfusion and ischemia. Enhancement of heart muscle could assist in differentiating healthy, ischemic, or infarcted myocardial tissue. Contrast agents selectively taken up in the liver may improve the detection of liver tumors or metastases. Selective enhancement of lymph nodes may allow tumor involvement to be detected directly, obviating the need to rely on crude size criteria for abnormality. The production of contrast agents with an affinity for specific tumors may also be possible. Radioactive-labeled antibodies against tumors are available for use in nuclear medicine, and appropriately labeled antibodies could carry paramagnetic compounds to tumor sites.

## GATING

Gated imaging is another technique for improving image quality in areas of the body in which involuntary patient motion is a problem. A patient can hold the head still for prolonged data acquisition, but the heartbeat and breathing cannot be suspended for the several minutes required for standard MRI studies. Even fast pulse sequences are susceptible to motion *artifact* from the beating heart. This is a problem when images of the chest or upper abdomen are desired. If special techniques are not used, part of the MRI signal may be obtained when the heart is contracted (systole) and part when the heart is relaxed (diastole). When information is combined into one image, the heart appears blurred. This problem is analogous to photographing a moving subject with a long shutter speed. Similar problems in MRI occur with the different phases of respiration.

*Gating* techniques are used to organize the signal so that only the signal received during a specific part of the cardiac or respiratory cycle is used for image production (Fig. 36-15). Gated images may be obtained in one of two ways. In one technique of cardiac gating, the imaging pulse sequence is initiated by the heartbeat (usually monitored by an ECG). Thus the data collection phase of the pulse sequence occurs at the same point in the cardiac cycle. Another method is to obtain data throughout the cardiac cycle but record the point in the cycle that each group of data was obtained. After enough data are collected, the data are reorganized so all data recorded within a certain portion of the cardiac cycle are collated together; for example, data collected during the first eighth of the cycle, second eighth of the cycle, etc. Each grouping of data can be combined into a single image, producing multiple images at different times in the cycle.



**Fig. 36-15** Gated images of the heart in different phases of the cardiac cycle. Imaging was obtained continuously, with incoming data subdivided into various portions of the cardiac cycle. **A**, Left ventricular outflow tract (LVOT) and **B**, short axis images. Anatomy demonstrated includes the aorta (A), left ventricle (LV), left ventricular wall (LVW), pulmonary artery (PA), right ventricle (RV), and sternal wires resulting in MR signal void (S).



The gating techniques are analogous to obtaining high-quality pictures of eight children on a spinning merry-go-round with a video camera in which the image from a single frame is of insufficient quality. If an image of only one of the children is desired, one video frame could be shot each time the child came into the video viewfinder. Later all the frames could be combined into one high-quality image. This is equivalent to the first gating technique. Alternately, if pictures of all the children are desired, the video camera could be run continuously, with documentation of which frames have which child in them. Later all the frames showing the first child could be matched together, all the frames showing the second child could be matched, and so forth. The result would be eight pictures, each showing one of the children. This is equivalent to the second gating technique.

## OTHER CONSIDERATIONS

When MRI was introduced, quite long imaging times were required to obtain enough information to reconstruct the sectional images. For most routine imaging this remains the standard. With advances in technology, however, it has become possible to quickly (within seconds) obtain enough data to reconstruct an image by using special fast-imaging pulse sequences. These fast-imaging pulse sequences are becoming more popular for specialized applications such as the obtainment of a dynamic series of images after IV administration of contrast agents. In many such sequences, fluid has a high signal intensity. This can produce a myelogramlike effect in studies of the spine or an arthrogramlike effect in evaluation of joint fluid (see Fig. 36-9). Quality assurance is important in a complex technology such as MRI. Calibration of the unit is generally performed by service personnel. However, routine scanning of phantoms by the technologist can be useful for detecting any problems that may develop.

## Clinical Applications

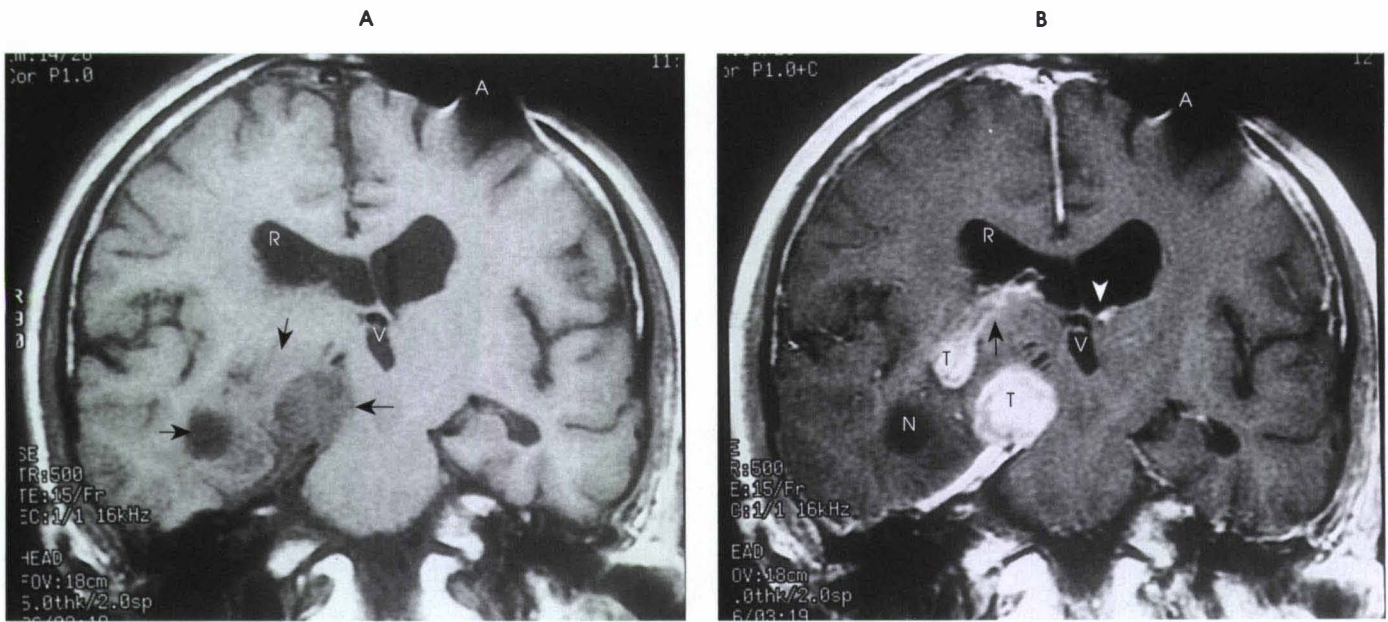
### CENTRAL NERVOUS SYSTEM

MRI is superior to CT for imaging the posterior fossa, which is the portion of the brain that includes the cerebellum and brainstem. Artifact from the dense bone of the surrounding skull obscures this area in CT. This area is artifact-free with MRI because there is little MRI signal from bone (see Fig. 36-11).

In general the absence of bone artifact with MRI is a distinct advantage over CT. However, the inability to image calcified structures can be a disadvantage when the lesion is more easily recognized because of its calcium content. Calcified granulomas of the lung or calcifications in certain other tumors are more difficult to detect with MRI than with CT.

MRI plays an increasing role in the routine examination of the brain. Because of the more natural contrast among tissues with MRI than with CT, the differentiation of gray matter from white matter in the brain is better with MRI (see Fig. 36-10). This enables MRI to be more sensitive than CT in detecting white matter disease such as multiple sclerosis.

Primary and metastatic brain tumors, pituitary tumors, and acoustic neuromas (tumors of the eighth cranial nerve) are generally better demonstrated by MRI than by CT. The use of gadolinium-based contrast agents has improved the ability of MRI to identify meningiomas (Fig. 36-16). MRI can detect cerebral infarction earlier than CT, but both tests provide similar information in subacute and chronic strokes.



**Fig. 36-16** Coronal MRI scan of the brain in a patient with a meningioma arising from the tentorium cerebelli. **A**, The precontrast T1-weighted image shows an inhomogeneous area of abnormality (*black arrows*), with mass effect elevating the right lateral ventricle (*R*) and midline shift of the third ventricle (*V*). **B**, This image was obtained at the same level after gadolinium enhancement. Active tumor (*T*) demonstrates high signal intensity, and the area of necrosis (*N*) does not enhance. Additional spread of tumor toward the ventricle (*arrows*) is visualized only after contrast enhancement. Choroid plexus (*white arrowhead*) enhances. Note that cerebrospinal fluid in the ventricles does not enhance. (*A*). Artifact from metal in skull defect from previous surgery.



**Fig. 36-17** Sagittal T2-weighted MRI scan through the upper cervical spine and brainstem. The high signal from cerebrospinal fluid (F) outlines the normal brainstem (B), cerebellum (C), and spinal cord (S), giving a myelogram-like effect without the use of contrast agents.



**Fig. 36-18** Sagittal T2-weighted image of the lumbar spine. The spinal canal is filled with high signal intensity cerebrospinal fluid (F) except for low signal intensity linear nerve roots running within the spinal canal. Normal vertebral disks have a high signal intensity nucleus pulposus (N). Desiccated disks (D) show low signal intensity. At L4-L5, note the herniated disk (arrow) protruding into the spinal canal and compressing the nerve roots.

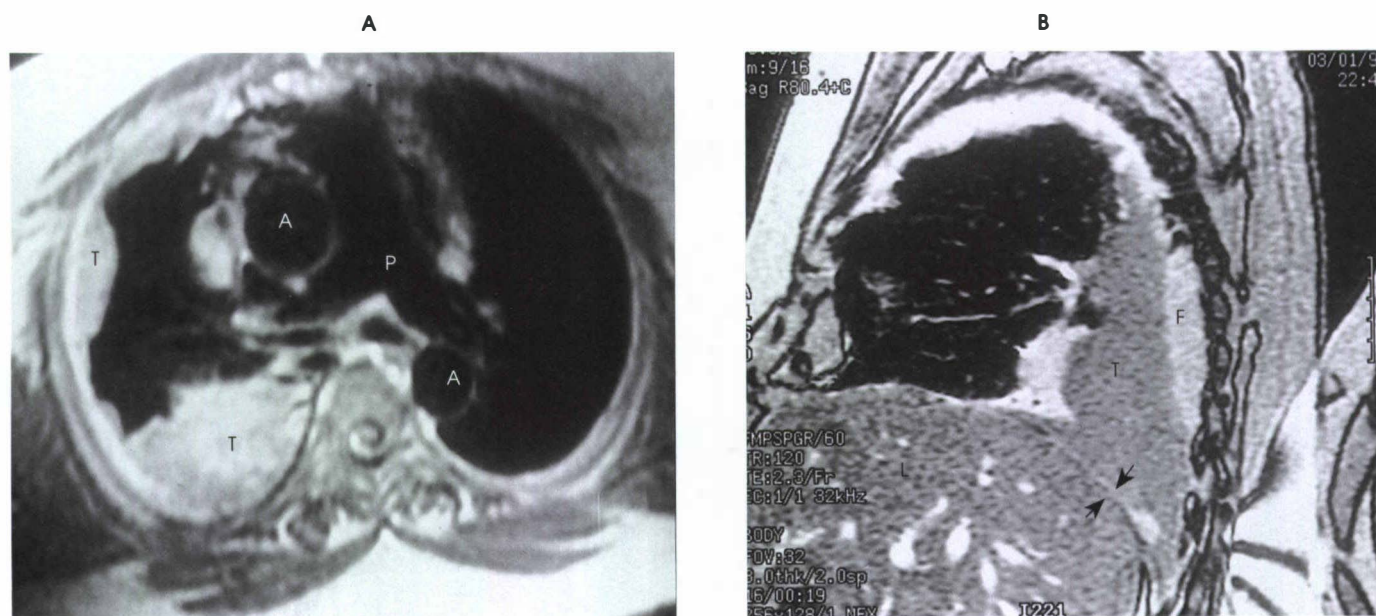


MRI has been successfully used to image the spinal cord. The absence of bone artifact allows excellent visualization of the contents of the neural canal. In addition, the technique can separate the spinal cord from the surrounding cerebrospinal fluid (CSF) without the use of the contrast agents (as required for CT) injected directly into the CSF during radiographic myelography (Fig. 36-17). MRI is sensitive in detecting spinal cord tumors and cystic changes of the spine (syringomyelia). MRI is also valuable in the detection of degenerated and herniated vertebral disks (Fig. 36-18).

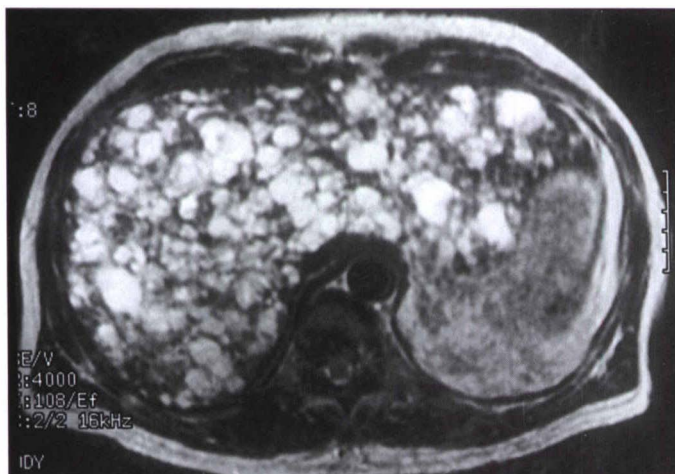
## CHEST

The chest would seem to be an ideal area for MRI examination because of its anatomy. The lungs have low signal as a result of low proton density, and the flowing blood in the great vessels of the chest also has a low MRI signal when standard pulse sequences are used. The heart muscle is well outlined by the lung and moving blood within the chambers. Furthermore, examination of the mediastinum is potentially fruitful because the normal structures of blood vessels and airways are of low signal. Any tumors of the mediastinum are easily seen as areas of MRI signal standing out against the normal low-signal surroundings (see Fig. 36-4). In addition, the ability of MRI to image in multiple planes may be helpful in evaluating tumor spread in the thoracic inlet, chest wall, or brachial plexus region (Fig. 36-19).

Nonetheless, difficulties with chest imaging remain because of cardiac and respiratory motion. Cardiac gating has markedly improved visualization of the heart with demonstration of septal defects and the cardiac valve leaflets. This is of great value in the study of congenital heart disease. Evaluation of the heart muscle for ischemia or infarction may require MRI contrast agents. Respiratory gating should help chest images.



**Fig. 36-19** MRI chest images in a patient with extensive mesothelioma. **A**, Image shows axial proton density-weighted image through the middle mediastinum. Because of flow void phenomenon, the ascending and descending aorta (A) and pulmonary artery (P) are well visualized. Extensive rind of tumor (T) is visualized. **B**, This sagittal fast sequence image was obtained with breath holding. Although this is a somewhat more noisy image, the lack of motion artifact allows evaluation of the diaphragm. A thin line of diaphragm and fluid (arrows) is intact between the liver (L) and tumor (T), indicating that the tumor has not invaded through the diaphragm. Some pleural fluid (F) is visualized around the tumor in the pleural space.

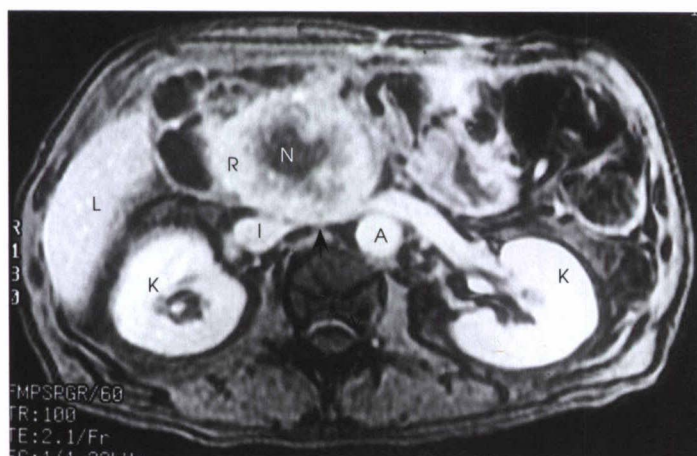


**Fig. 36-20** Axial heavily T2-weighted MRI scan through the liver in a patient with hemangioma. The multiple lesions of this tumor have virtually replaced the entire liver. No contrast agents were required to demonstrate these multiple liver lesions.

## ABDOMEN

Respiratory and cardiac motion also detract from upper abdominal images. Again, gating should be of assistance. Evidence exists that MRI is more sensitive than CT in detecting primary and metastatic tumors of the liver (Fig. 36-20). The suprarenals, kidneys, and retroperitoneal structures such as lymph nodes are seen well with MRI. However, limited evidence exists that MRI is superior to CT for abdominal imaging, particularly general screening for abnormalities. Visualization of the normal pancreas has been difficult with MRI.

MRI has some ability to predict the histologic diagnosis of certain abnormalities. For example, hepatic hemangiomas (common benign tumors of the liver) have a distinctive MRI appearance that can be helpful in ruling out other causes of hepatic masses. Patterns of enhancement with gadolinium-based contrast agents can assist in evaluating various tumors (Fig. 36-21).



**Fig. 36-21** Axial fast sequence MRI of the central abdomen in a patient with a pancreatic islet cell tumor after gadolinium injection. Enhancement of the rim of the mass (R) indicates necrosis (N) in a central portion of mass that does not enhance. Also well visualized is the relationship of the mass to vessels, such as compression (arrowhead) of left renal vein (V). A, Aorta; I, inferior vena cava; K, kidney; L, lower tip of liver.

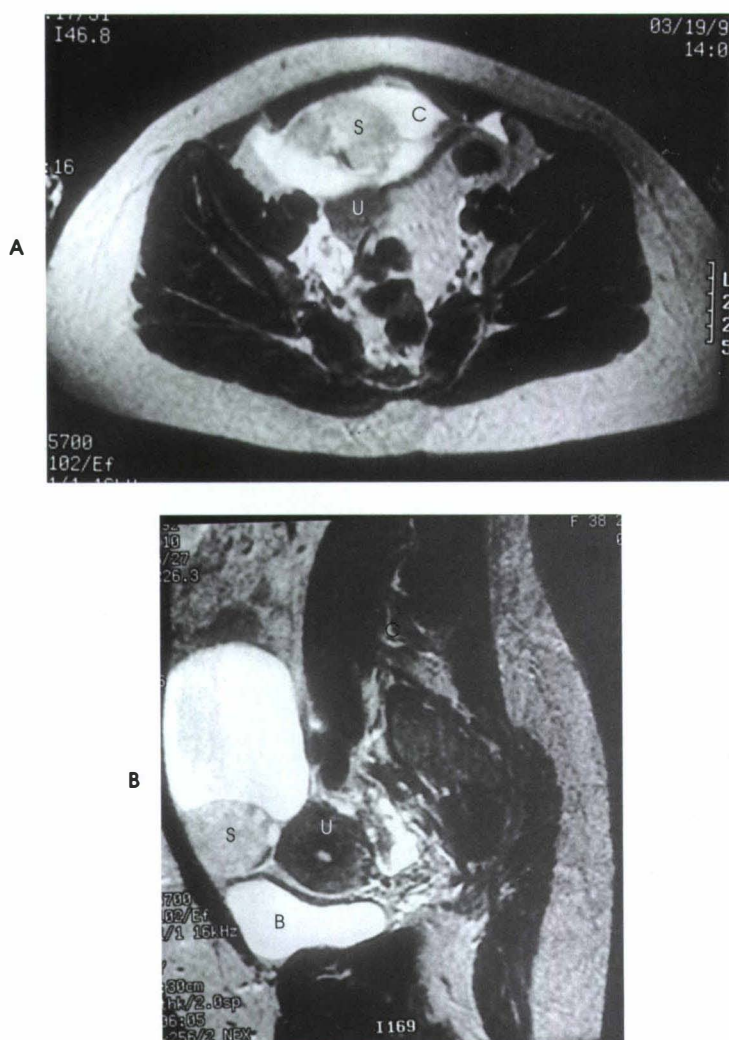


## PELVIS

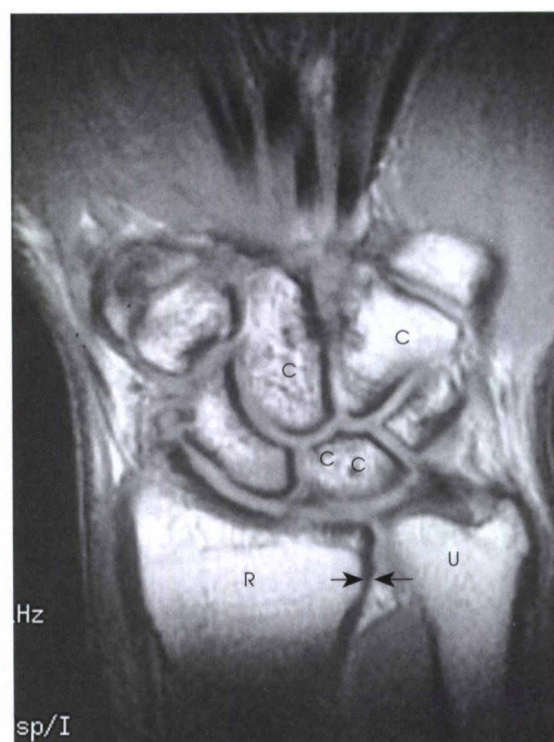
Respiratory motion has little effect on the structures in the pelvis. As a result, these structures can be better visualized than those in the upper abdomen. The ability of MRI to image in the coronal and sagittal planes is helpful in examining the curved surfaces in the pelvis. For example, bladder tumors are shown well, including those at the dome and base of the bladder that can be difficult to evaluate in the transverse dimension. In the prostate (see Fig. 36-13) and female genital tract (Fig. 36-22), MRI is useful in detecting neoplasm and its spread.

## MUSCULOSKELETAL SYSTEM

MRI produces excellent images of the limbs because involuntary motion is not a problem and MRI contrast among the soft tissues is excellent. The lack of bone artifact in MRI permits excellent visualization of the bone marrow (Fig. 36-23). In plain-film radiography and occasionally in CT, dense cortical bone is often hidden in the marrow space. However, as previously stated, calcium within tumors is better visualized with CT because of the lower MRI signal from calcium.



**Fig. 36-22** T2-weighted images through the pelvis of a woman. **A**, Axial image. **B**, Sagittal image. Both images show solid (S) and cystic (C) components of a large ovarian tumor. The relationship to the uterus (U) and bladder (B) is also shown well using multiple imaging planes.



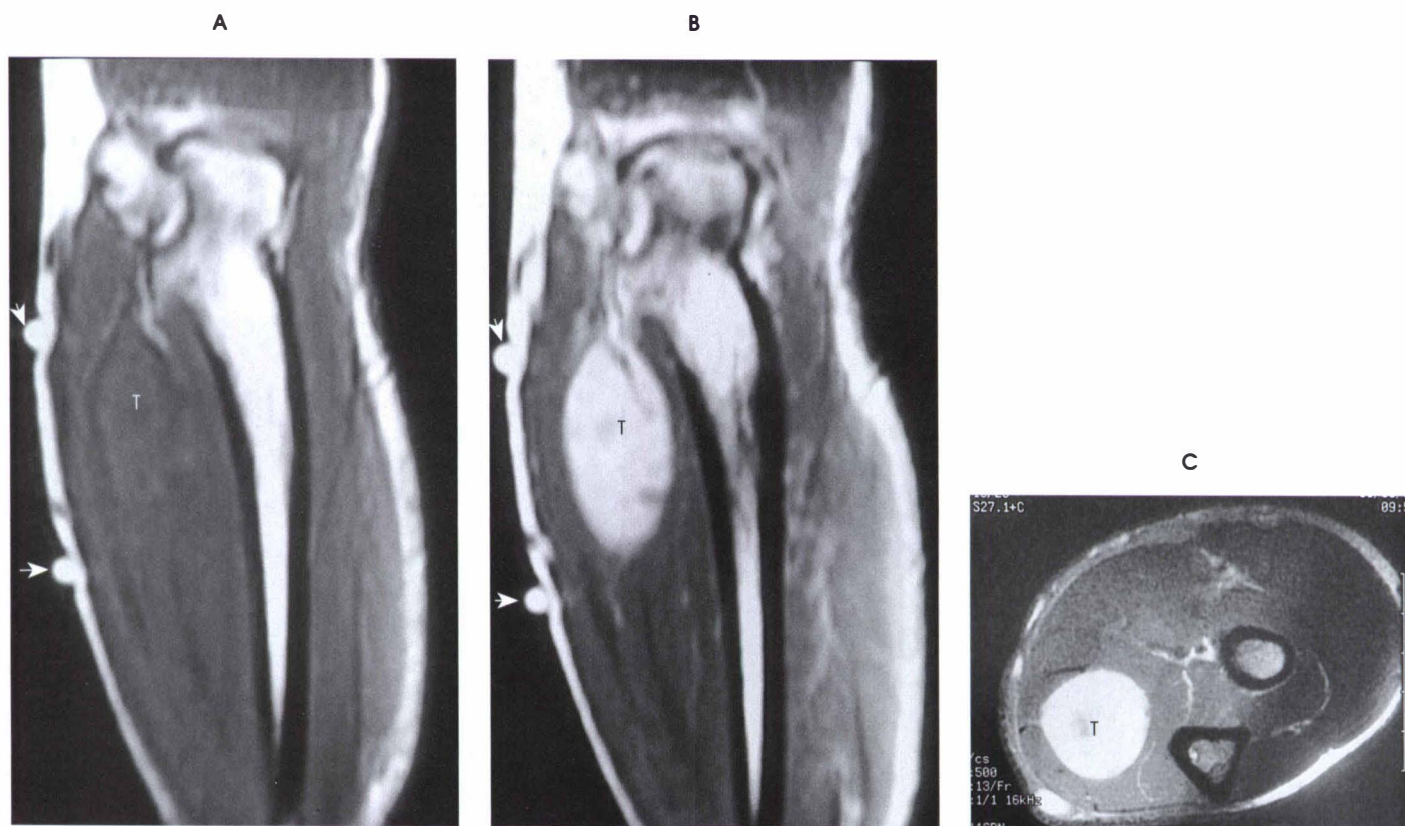
**Fig. 36-23** Coronal MRI scan of the wrist using a surface coil to improve visualization of superficial structures. Marrow within the carpal bones (C), radius (R), and ulna (U) has high signal as a result of its fat content. A thin black line of low-signal cortex (arrows) surrounds the marrow cavity of each bone, and trabecular bone can be seen as low signal detail interspersed within marrow.



Overall, the ability to image in multiple planes, along with excellent visualization of soft tissues and bone marrow, has rapidly expanded the role of MRI in musculoskeletal imaging. MRI is particularly valuable for the study of joints, and it is replacing arthrography and to a lesser extent arthroscopy in the evaluation of the injured knee (see Fig. 36-9), ankle, and shoulder. Small joints also are well evaluated with MRI. Local staging of soft tissue and bone tumors is best accomplished with MRI (Fig. 36-24). Early detection of ischemic necrosis of bone is another strength of MRI (Fig. 36-25).

## VESSELS

The contrast between soft tissue structures and the typical low signal of flowing blood using standard pulse sequences gives MRI the ability to visualize thrombosis within major vessels such as the venae cavae or the tumor invasion of these vessels. Vascular anomalies, dissections, and coarctations also can be well evaluated by MRI. Special pulse sequences using standard gadolinium-based contrast agents now allow MRI visualization of moving blood within the vascular system (Fig. 36-26). These noninvasive angiogramlike images of the vessels (magnetic resonance angiograms) improve the visualization of vascular lesions.



**Fig. 36-24** Coronal and axial images of the arm obtained with T1 weighting. **A**, Image obtained before contrast administration. **B** and **C**, images obtained after IV gadolinium injection. Little contrast between neurofibroma (*T*) and normal tissue is seen before enhancement; the tumor is markedly enhanced after gadolinium injection. The location of the tumor is evident before contrast injection, only because the palpable mass is marked externally with vitamin E capsules (*arrowheads*). The relationship of the tumor to muscles and bone is evident in the coronal and axial sections.



**Fig. 36-25** Coronal T1-weighted image of the ankle. The bone marrow demonstrates high signal intensity because of fat. A focal area (*N*) of devascularization at the dome of the talus (*T*) shows low signal intensity. However, the overlying bony cortex and cartilage are intact. *S*, Tibia; *F*, fibula; *C*, calcaneus.



**Fig. 36-26** Contrast-enhanced MRA of the abdominal aorta (*arrow*), showing the renal arteries (*arrowheads*) and iliac bifurcations (*broken arrows*).

The carotid arteries in the neck (Fig. 36-27) and their intracranial branches (Fig. 36-28) can be studied for aneurysms, arteriovenous malformations, plaques, stenoses, and occlusions. Small arteries in the peripheral vascular system also can be studied. Flow studies of the thoracic and abdominal vessels are more difficult, but specialized fast sequences permit cardiac gated images to be obtained during a single breath hold. Typical uses include evaluation of the thoracic aorta for dissections, the abdominal aorta for aneurysms, and the renal arteries for stenoses.

Two common techniques to obtain images of flowing blood are time-of-flight and phase-contrast MRA. Using either of these techniques, magnetic resonance angiograms can be obtained in two-dimensional (obtaining a series of slices) or three-dimensional images. In time-of-flight imaging, a special pulse sequence is used that suppresses the MRI signal from the anatomic area under study (see Fig. 36-27). Consequently, an MRI signal is given only by material that is outside the area of study when the signal-suppressing pulse occurs. Thus incoming blood makes vessels appear bright, whereas stationary tissue signal is suppressed. Phase-contrast imaging takes advantage of the shifts in phase, or orientation, experienced by magnetic nuclei moving through the MRI field (see Fig. 36-28). Special pulse sequences enhance these effects in flowing blood, producing a bright signal in vessels when the unchanging signal from stationary tissue is subtracted.

Gadolinium-based contrast agents also can be useful in MRA studies. Many MRA schemes use fast pulse sequences to reduce overall imaging time, particularly with three-dimensional vascular imaging. For better contrast in images obtained with fast sequences, a gadolinium-based intravascular contrast agent may be injected to shorten the T1 of blood in order to increase its signal intensity.

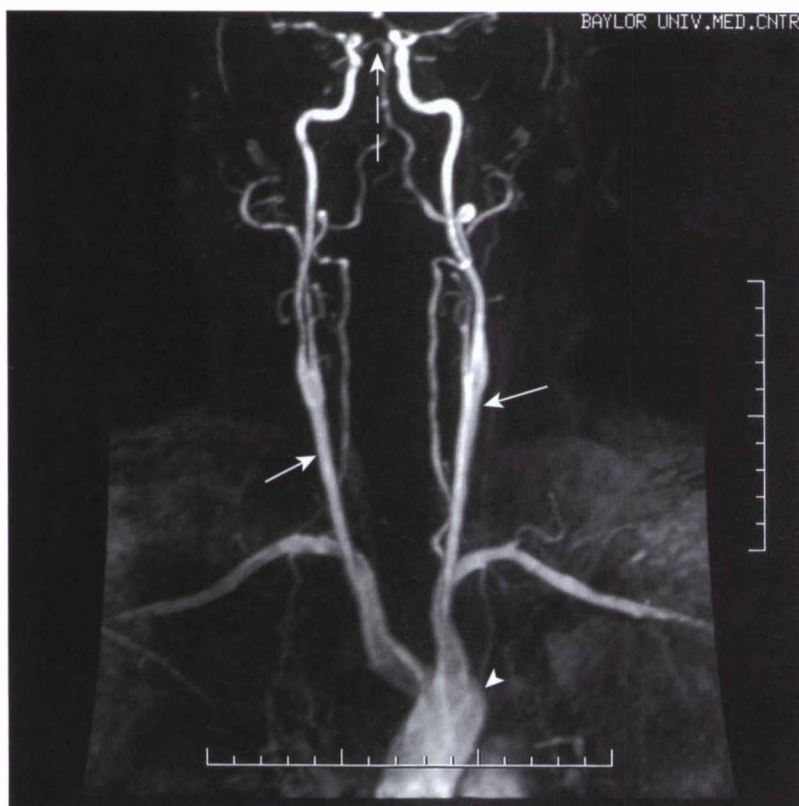


Fig. 36-27 Contrast-enhanced MRA showing the carotid arteries (arrows) from the aortic arch (arrowhead) to the circle of Willis (broken arrow).



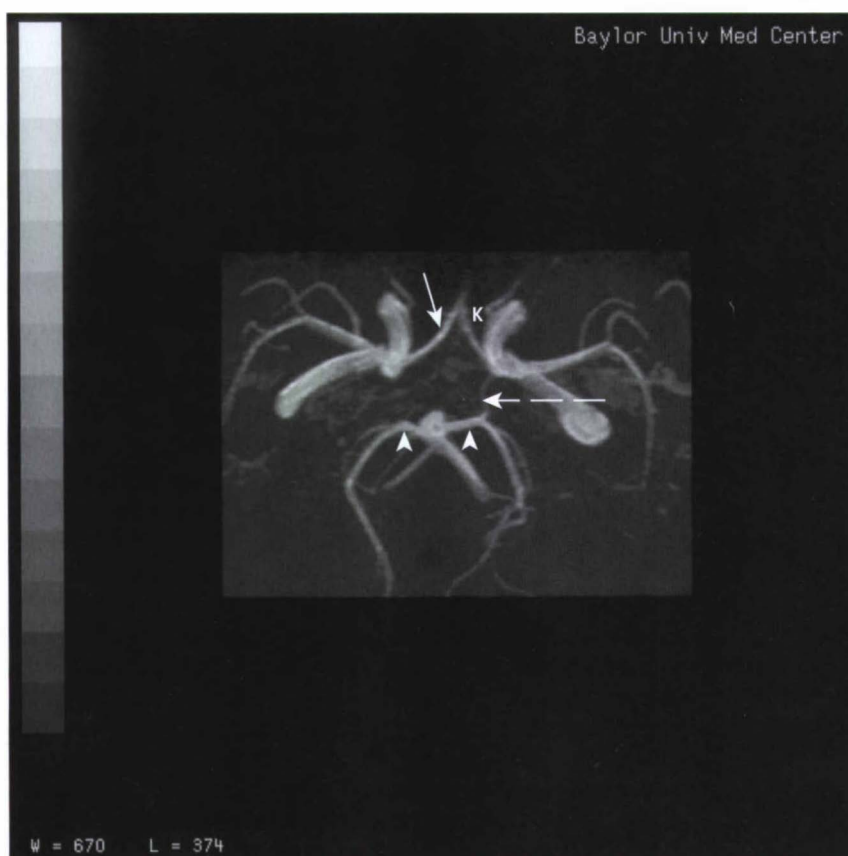
## DIFFUSION AND PERFUSION

The sensitivity of MRI to motion can be both a handicap and a potential source of information. For example, motion artifacts interfere with upper abdominal images that are affected by heart and diaphragmatic motion, yet flow-sensitive pulse sequences can image flowing blood in blood vessels.

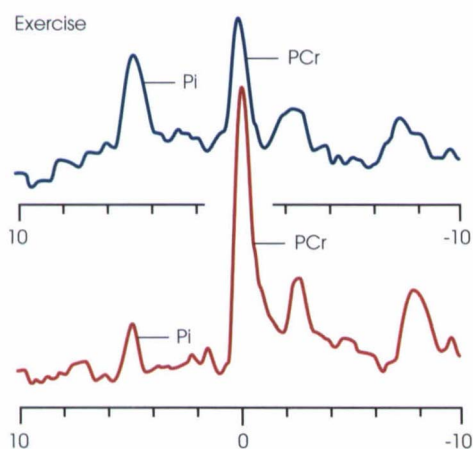
Specialized techniques that can image the *diffusion* and *perfusion* of molecules within matter are currently under investigation. Molecules of water undergo random motion within tissues, but the rate of this diffusion is affected by cellular membranes and macromolecules, as well as by temperature. Molecules are also moving slowly through tissues with the perfusion of blood into the small capillary vessels.

Tissues have structure, and this structure affects both the rates of diffusion and perfusion and their direction; in other words, diffusion and perfusion are not entirely random in a structured tissue. These microscopic motions can be detected by specialized MRI pulse sequences that can image their rate and direction. Diffusion and perfusion motion differ between tissue types. For example, diffusion patterns of gray matter in the brain differ from the diffusion patterns in more directionally oriented fiber tracts of white matter. For technical reasons, most diffusion and perfusion imaging research has focused on the central nervous system.

Diffusion and perfusion imaging can produce clinically significant images that may help in the understanding of white matter degenerative diseases (e.g., multiple sclerosis, ischemia, infarction), the development of possible therapies to return blood flow to underperfused brain tissue, and the characterization of brain tumors. Similar applications for the rest of the body may be developed if technical difficulties, particularly those related to patient motion such as breathing, can be overcome.



**Fig. 36-28** MR angiogram of the intracranial vessels demonstrated in a submentovertex projection showing the left and right anterior cerebral arteries (arrows). Also shown are the posterior cerebral arteries (arrowheads), which join the posterior communicating artery (broken arrow) to form the circle of Willis. Note only one posterior communicating artery is seen.

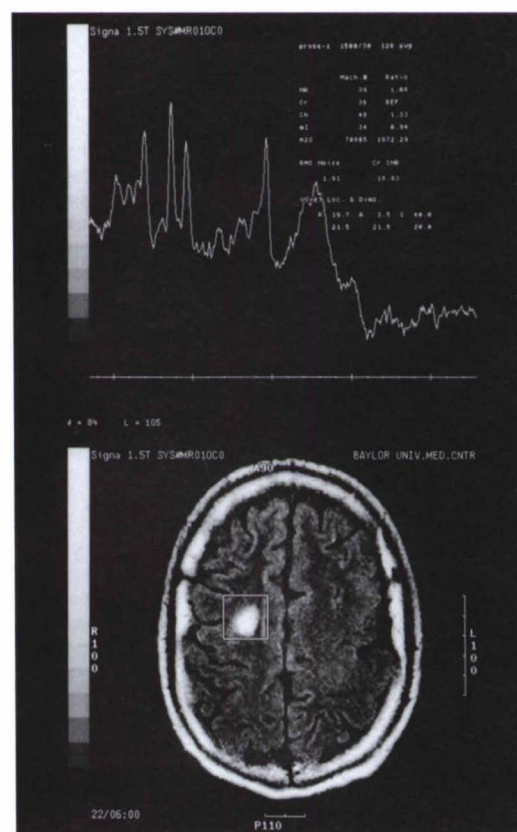


**Fig. 36-29** Spectra from human muscle before (red line) and during (blue line) exercise. The thin horizontal lines represent separate baselines for each spectrum. Each peak represents a different chemical species, and the area under the peak down to the baseline indicates the amount of substance present. The inorganic phosphate (Pi) peak increases with exercise as energy-rich phosphocreatine (PCr) is used to provide energy for muscle contraction.

## Spectroscopy

With MRI it is generally assumed that each nucleus in a specific small area in space is exposed to the same magnetic field and thus precesses at a particular frequency and releases energy of that frequency. If the magnetic field varies across the imaging volume in a known way, frequency can be used as one determinant of the location from which a signal is originating. A one-to-one relationship between frequency and location is an integral part of creating the image in MRI. In actuality, however, each nucleus in a small area in space does not detect precisely the same magnetic field. The externally imposed field is the same, but the magnetic environments of the nuclei differ, depending on the magnetic effects of other nearby atoms. These differences in frequencies are small and generally do not affect the image significantly; each signal is still placed in the correct position in the image. In magnetic resonance spectroscopy a detailed graph of signal strength against frequency is produced instead of an image. The graphs produced are called *spectra*.

Spectroscopy is essentially a tool for clinical analysis that can determine the relative quantity of chemical substances within a volume of tissue. Because the frequency differences are small and electronic noise is relatively high, large volumes of tissue must be studied to receive enough total signal to produce useful spectra. Nevertheless, it is possible to obtain spectra from organs (e.g., muscle, liver) or large masses to examine normal physiologic changes (e.g., with exercise), chemical alterations in persons with metabolic diseases, or differences in chemical composition between normal tissue and tumors or other pathologic processes (Fig. 36-29). Spectroscopy of the CNS is now widely accepted and routinely used (Fig. 36-30).



**Fig. 36-30** Routine spectroscopy technique in a 31-year-old male patient. The study shows toxoplasmosis with schizencephaly and pachygyria.

## Conclusion

MRI is an exciting form of imaging that examines properties of tissue never before visualized. Thousands of publications have attested to the effectiveness of MRI for evaluating various clinical conditions. However, it is more difficult to prove that MRI is clinically superior to all other imaging modalities. Although comparative studies have been completed for some clinical situations, more extensive research is needed for others. In some cases, various imaging modalities are complementary.

MRI is an expensive imaging technology. With the recent increased emphasis on cost constraints, the use of MRI will not expand as quickly as it otherwise might have. MRI will also have to compete with other modalities for an imaging "niche." Nevertheless, MRI is clearly the technique of choice in many clinical situations. MRI applications continue to increase, in part because of the extreme flexibility of this imaging modality. New pulse sequences can be programmed into the computer, and new contrast agents are under development; both provide new information about anatomy and pathology. Thus, despite cost constraints, the depth and breadth of the role of MRI in diagnostic imaging continue to increase.

## Definition of Terms

**antenna** Device for transmitting or receiving radio waves.

**artifact** Spurious finding in or distortion of an image.

**attenuation** Reduction in energy or amount of a beam of radiation when it passes through tissue or other substances.

**coil** Single or multiple loops of wire (or another electrical conductor such as tubing) designed to produce a magnetic field from current flowing through the wire or to detect a changing magnetic field by voltage induced in the wire.

**contrast** Degree of difference between two substances in some parameter. The parameter varying depending on the technique used; for example, attenuation in radiographic techniques or signal strength in MRI.

**cryogenic** Relating to extremely low temperature (see *superconductive magnet*).

**diffusion** Spontaneous random motion of molecules in a medium; a natural and continuous process.

**echo planar imaging** Fast pulse sequence that can be used to create magnetic resonance images within a few seconds.

**fat suppressed images** Images in which the fat tissue in the image is made to be of a lower, darker, signal intensity than the surrounding structures.

**frequency** Number of times that a process repeats itself in a given period; for example, the frequency of a radio wave is the number of complete waves per second.

**fringe field** That portion of the magnetic field extending away from the confines of the magnet that cannot be used for imaging but can affect nearby equipment or personnel.

**gating** Organizing the data so that the information used to construct the image comes from the same point in the cycle of a repeating motion, such as a heartbeat. The moving object is "frozen" at that phase of its motion, reducing image blurring.

**gauss (G)** Unit of magnetic field strength (see *tesla*).

**gradient echo** Fast pulse sequence that is often used with three-dimensional imaging to generate T2-weighted images.

**inversion recovery** Standard pulse sequence available on most MRI imagers, usually used for T1-weighted images. The name indicates that the direction of longitudinal magnetization is reversed (inverted) before relaxation (recovery) occurs.

**magnetic resonance (MR)** Process by which certain nuclei, when placed in a magnetic field, can absorb and release energy in the form of radio waves. This technique can be used for chemical analysis or for the production of cross-sectional images of body parts. Computer analysis of the radio wave data is required.

**noise** Random contributions to the total signal that arise from stray external radio waves, imperfect electronic apparatus, etc. Noise cannot be eliminated, but it can be minimized; it tends to degrade the image by interfering with accurate measurement of the true MRI signal, similar to the difficulty in maintaining a clear conversation in a noisy room.

**nuclear magnetic resonance (NMR)** Another name for magnetic resonance, term is not commonly used.

**nucleus** Central portion of an atom, composed of protons and neutrons.

**paramagnetic** Referring to materials that alter the magnetic field of nearby nuclei. Paramagnetic substances are not themselves directly imaged by MRI but instead change the signal intensity of the tissue where they localize, thus acting as MRI contrast agents. Paramagnetic agents shorten both the T1 and T2 of the tissues they affect, actions that tend to have opposing effects on signal intensity. In clinical practice, agents are administered in a concentration in which either T1 or T2 shortening predominates (usually the former) to provide high signal on T1-weighted images.

**perfusion** Flow of blood through the vessels of an organ or anatomic structure; usually refers to blood flow in the small vessels (e.g., capillary perfusion).



**permanent magnet** Object that produces a magnetic field without requiring an external electricity supply.

**precession** Rotation of an object around the direction of a force acting on that object. This should not be confused with the axis of rotation of the object itself; for example, a spinning top rotates on its own axis, but it may also precess (wobble) around the direction of the force of gravity that is acting on it.

**proton density** Measure of proton (i.e., hydrogen, because its nucleus is a single proton) concentration (number of nuclei per given volume). One of the major determinants of MRI signal strength in hydrogen imaging.

**pulse** See *radiofrequency (RF) pulse*.

**pulse sequence** Series of radio-wave pulses designed to excite nuclei in such a way that their energy release has varying contributions from proton density, T1, or T2 processes.

**rapid acquisition recalled echo** Commonly known as *fast*, or *turbo*, *spin echo*; a fast pulse sequence used to rapidly create spin-echo-like T2-weighted images.

**raw data** Information obtained by radio reception of the MRI signal as stored by a computer. Specific computer manipulation of these data is required to construct an image from them.

**radiofrequency (RF) pulse** A short burst of radio waves. If the radio waves are of the appropriate frequency, they can give energy to nuclei that are within a magnetic field by the process of *magnetic resonance*. The length of the pulse determines the amount of energy given to the nuclei.

**relaxation** Return of excited nuclei to their normal, unexcited state by the release of energy.

**relaxation time** Measure of the rate at which nuclei, after stimulation, release their extra energy.

**resistive magnet** Simple electromagnet in which electricity passing through coils of wire produces a magnetic field.

**resonance** Process of energy absorption by an object that is tuned to absorb energy of a specific frequency only. All other frequencies will not affect the object; for example, if one tuning fork is struck in a room full of tuning forks, only those forks tuned to that identical frequency will vibrate (resonate).

**signal** In MRI, the induction of current into a receiver coil by the precessing magnetization.

**slice** Cross-sectional image; can also refer to the thin section of the body from which data are acquired to produce the image.

**spectroscopy** Science of analyzing the components of an electromagnetic wave, usually after its interaction with some substance (to obtain information about that substance).

**spin echo** Standard MRI pulse sequence that can provide T1-, T2-, or proton density-weighted images. The name indicates that a declining MRI signal is refocused to gain strength (like an echo) before it is recorded as raw data.

**spin-lattice relaxation** Release of energy by excited nuclei to their general environment. One of the major determinants of MRI signal strength. T1 is a rate constant measuring spin-lattice relaxation.

**spin-spin relaxation** Release of energy by excited nuclei as a result of interaction among themselves; one of the major determinants of MRI signal strength. T2 is a rate constant measuring spin-spin relaxation.

**superconductive magnet** Electromagnet in which the coils of wire are cooled to extremely low temperature so that the resistance to the conduction of electricity is nearly eliminated (superconductive).

**superparamagnetic** Material that has a greater effect with a magnetic field; it can dramatically decrease the T2 of tissues, causing a total loss of signal by the absorbing structures.

**T1** Rate constant measuring spin-lattice relaxation.

**T2** Rate constant measuring spin-spin relaxation.

**Transverse plane** A plane that extends across the axis of the body from side to side, dividing the body part into upper and lower portions.

**tesla (T)** Unit of magnetic field strength; 1 tesla equals 10,000 gauss or 10 kilogauss (other units of magnetic field strength). The Earth's magnetic field approximates 0.5 gauss.

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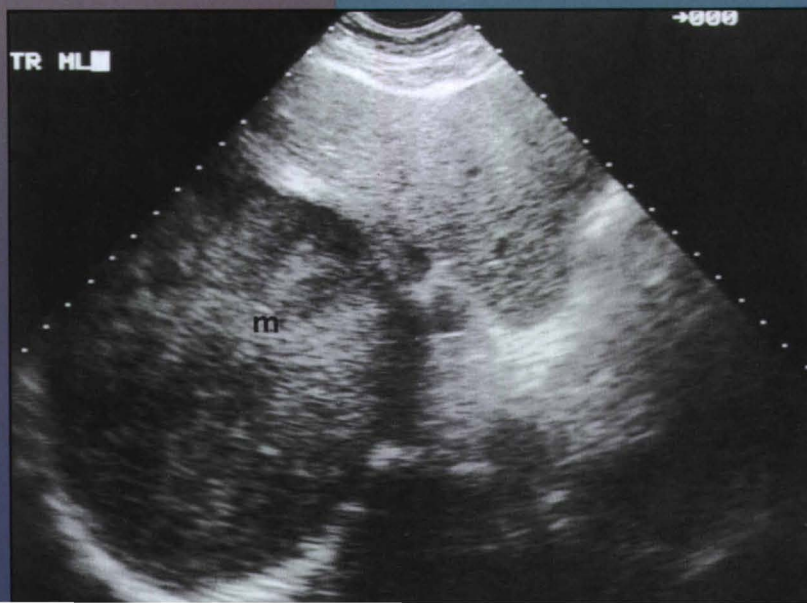
# DIAGNOSTIC ULTRASOUND

SANDRA L. HAGEN-ANSERT

Transverse scan over the inhomogeneous right lobe of the liver showing a huge complex mass (*m*) diagnosed as hepatocellular carcinoma.

## OUTLINE

Principles of diagnostic ultrasound, 416  
Historical development, 417  
Physical principles, 417  
Anatomic relationships and landmarks, 419  
Clinical applications, 419  
Cardiologic applications, 452  
Conclusion, 457  
Definition of terms, 458





## Principles of Diagnostic Ultrasound

*Diagnostic ultrasound*,\* sometimes called *diagnostic medical sonography*, *sonography*, *ultrasonography*, *vascular sonography*, or *echocardiography*, has become a clinically valuable imaging technique over the past four decades. Ultrasound differs from diagnostic radiography in that it uses nonionizing, high-frequency sound waves to generate an image of a particular soft tissue structure in the body. Reflections from soft tissue interfaces of homogeneous, fluid-filled, or solid organs, tumor masses, and muscles located within the body may be imaged with ultrasound.

The blood flow velocities within a vessel may be calculated with the *Doppler* technique. *Pulsed-wave (PW)*, *continuous-wave (CW)*, and *color-flow Doppler* techniques have been shown to be clinically useful in determining not only the direction of blood flow within vessels but also the flow resistance, turbulence, or *regurgitation* of blood within the vessel or cardiac chamber.

Diagnostic ultrasound has many advantages over other imaging techniques. One advantage is its mobility as the ultrasound system may be easily moved into the surgical suite, emergency department, neonatal nursery, or intensive care unit. The ultrasound system may also be wheeled onto a van to provide services for small hospitals and clinics that may not have the patient load to employ a full-time sonographer. Ultrasound is more cost-effective than computed tomography (CT), magnetic resonance imaging (MRI), and angiography since ultrasound equipment is less expensive and minimal supplies are needed to run the ultrasound laboratory.

\*Almost all italicized words on the succeeding pages are defined at the end of this chapter.

Ultrasound, once considered a *noninvasive technique*, now includes examinations that involve transvaginal, transrectal, and transesophageal transducers. Intraluminal transducers have provided the cardiovascular surgeons a “window” for viewing the *intima* of the coronary arteries during a cardiac catheterization or as part of an open cardiovascular surgical case. Three- and four-dimensional reconstructions of the ultrasound image have produced exquisite images of fetal anatomy and other anatomical structures within the body. Contrast media have been utilized by cardiologists to provide improved visualization of the cardiac muscle found in ischemic heart disease. Radiologists are clinically investigating the usefulness of contrast media to enhance tumor invasion in the liver, gallbladder, pancreas, and spleen. Gynecologists have utilized contrast to investigate the endometrial cavity and fallopian tubes.

### CHARACTERISTICS OF THE DIAGNOSTIC MEDICAL SONOGRAPHER

The diagnostic medical sonographer performs ultrasound studies and gathers diagnostic imaging data under the direct or indirect supervision of a physician. The sonographer has the ability to “look” inside abdominal and pelvic organs in the fetus, neonate, pediatric, and adult population. The cardiac sonographer has the ability to image the dynamic function of the heart under normal and stressful conditions.

The sonographer approaches the evaluation of the patient in a manner very different from the radiographer. The principal difference lies in the sonographer’s knowledge of detailed anatomy and pathophysiology. An understanding of the three-dimensional anatomy and reconstruction of the sonographic image is necessary for the sonographer to produce an adequate image.

The sonographer must have intellectual curiosity because the examination of each patient can present special challenges. This imaging professional needs to have an analytic capability coupled with perseverance to obtain high-quality images. Furthermore, the sonographer must enjoy both working with complex equipment and communicating with patients.

Educational opportunities are available for the student interested in sonography and may be found primarily in two or four year colleges. Sonography is a career in which specialized skills and abilities make a difference. Although many sonographers work in hospitals or clinics, others have found productive careers with ultrasound companies in product design, marketing, research, application specialists, or education. The work in ultrasound provides day-to-day variety and often allows a flexible schedule. Many employment opportunities are available, and salaries are attractive.

Of course, sonography is not a flawless profession. The work may be stressful and demanding particularly in situations in which patient loads are increased and staff members are reduced. The lack of cure for certain diseases may lead to frustration, and daily contact with a high-risk obstetric patient with an abnormal fetus may lead to depression. Job tasks can be physically demanding in the high volume hospital and clinical outpatient laboratory. Constant manipulation of patients and positioning of the transducer may lead to muscle fatigue and stress-related inflammation problems of the wrist, arm, and shoulder if proper care is not taken.

### RESOURCE ORGANIZATIONS

Resource organizations devoted to exclusively to ultrasound include the American Society of Echocardiography (ASE), the Society of Diagnostic Medical Sonographers (SDMS), the American Institute of Ultrasound in Medicine (AIUM), the Society of Radiologists in Ultrasound (SRU), and the Society of Vascular Technology (SVT).



## Historical Development

The development of *sonar* was the precursor to medical ultrasound. Sonar equipment was initially constructed for the defense efforts during World War II to detect the presence of submarines. Various investigators later proved that ultrasound had a valid contribution to make in medicine.

In 1947 Dussick positioned two transducers on opposite sides of the head to measure ultrasound transmission profiles. He also discovered that tumors and other intracranial lesions could be detected by this technique. In the early 1950s Dussick, with Heuter, Bolt, and Ballantyne, continued to use *through-transmission* techniques and computer analysis to diagnose brain lesions in the intact skull. However, they discontinued their studies after concluding that the technique was too complicated for routine clinical use.

In the late 1940s Douglas Howry (a radiologist), John Wild (a diagnostician interested in tissue characterization), and George Ludwig (interested in reflections from gallstones) independently demonstrated that when ultrasound waves generated by a piezoelectric crystal transducer were transmitted into the human body, these waves would be returned to the transducer from tissue interfaces of different *acoustic impedances*. At this time, research efforts were directed toward transforming naval sonar equipment into a clinically useful diagnostic tool.

In 1948 Howry developed the first ultrasound scanner, consisting of a cattle watering tank with a wooden rail anchored along the side. The transducer carriage moved along the rail in a horizontal plane, while the object to be scanned and the transducer were positioned inside the water tank. (An early ultrasound scanner is shown on the title page of this chapter.)

Echocardiographic techniques were developed by Hertz and Edler in 1954 in Sweden. These investigators were able to distinguish normal heart valve motion from the thickened, calcified valve motion seen in patients with rheumatic heart disease. Then in 1957 an early obstetric contact-compound scanner was built by Tom Brown and Ian Donald in Scotland. This scanner was used primarily to evaluate the location of the placenta and to determine the gestational age of the fetus.

Further developments have resulted in the real-time ultrasound instrumentation used in hospitals and clinics today. High-frequency transducers with improved *resolution* now allow the sonographer to accumulate several images per second at a rate of up to 30 frames per second. Diagnostic ultrasound as used in clinical medicine has not been associated with any harmful biologic effects and is generally accepted as a safe modality.

## Physical Principles

### PROPERTIES OF SOUND WAVES

An *acoustic wave* is a propagation of energy that moves back and forth or vibrates at a steady rate. Sound waves are mechanical oscillations that are transmitted by particles in a gas, liquid, or solid medium. Generated by an external source, ultrasound is the transmission of high-frequency mechanical vibrations greater than 20 kHz through a medium.

Ultrasound refers to sound waves beyond the audible range (16,000 to 20,000 cycles/second). Diagnostic applications of ultrasound use frequencies of 1 to 10 million cycles/second, (1 to 10 MHz). The ultrasound beam is produced from a transducer by the piezoelectric effect. The Curie brothers described the *piezoelectric effect* in 1880, when they observed that when certain crystals such as quartz undergo mechanical deformation a potential difference develops across the two surfaces of the crystals.

### Acoustic impedance

The *ultrasound wave* is similar to a light beam in that it may be *focused*, *refracted*, *reflected*, or *scattered* at interfaces between different media. At the junction of two media of different acoustic properties, an ultrasound beam may be reflected, depending on the difference in acoustic impedance between the two media and the angle at which the beam hits the interface (Fig. 37-1).

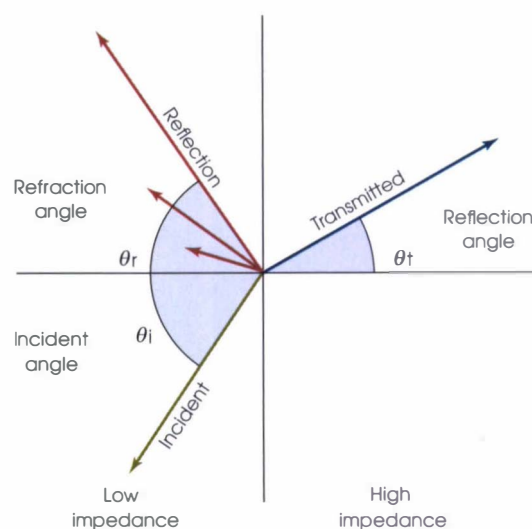


Fig. 37-1 Relationship among incident, reflected, and transmitted waves.

### Velocity of sound

The *velocity of sound* in a *medium* is determined by the *density* and elastic properties of the medium. The velocity of sound differs greatly among air, bone, and soft tissue, but varies only slightly from one soft tissue to another. Sound transmission is impeded by air-filled structures such as the lungs and stomach or by gas-filled structures such as the bowel. However, sound is *attenuated* through most bony structures.

### TRANSDUCER SELECTION

In ultrasound, transducers are used to generate the ultrasonic energy. The major component of an ultrasound transducer is the piezoelectric element. The piezoelectric materials are capable of converting one form of energy into another. Transducer designs differ according to the application for which it is used. A *curved linear array transducer* has a narrow rectangular surface with a slight convex curve. There are multiple elements within the transducer that are pulsed sequentially to produce an image. This type of transducer is used for larger surface areas such as the abdomen or with an obstetrical patient. The superficial areas (breast, thyroid, scrotum, and limbs) use a smaller linear array transducer with a flat surface for better contact. The cardiac studies are performed with a small faced sector phased array transducer.

Transducers also have different frequencies ranging from a low frequency of 1 MHz to higher frequencies of 12 to 20 MHz. A good rule to remember is that the smaller the object to be imaged, the higher the transducer frequency. The higher frequency provides better resolution but does not contain enough strength to penetrate deep structures. An example would be found in an abdominal study: an adult patient would require a curved array transducer with a 3 to 4 MHz frequency; a child would require a smaller curved array with a 5 to 7 MHz frequency transducer. A premature infant may require a tiny sector 12 MHz transducer to fit into the soft spot on the anterior fontanelle.

### REAL-TIME IMAGING, DOPPLER EFFECT, AND COLOR FLOW DOPPLER

*Real-time imaging* is the presentation of multiple image frames per second over selected areas of the body. The transducer may be composed of several elements that can be electronically focused and fired in rapid sequence to produce a real-time image. Thus structures are visible as they change position in time. With this dynamic imaging it is possible to see, for example, pulsatile vascular and cardiac structures, diaphragm motion, and peristalsis in the bowel and stomach.

The *Doppler effect* refers to a change in frequency when the motion of laminar or turbulent flow is detected within a vascular structure. *Color flow Doppler* is a technique that assigns a color scale to the change in frequency or Doppler shift. Generally, red signifies a shift toward the transducer, whereas blue signifies a shift away from the transducer.

### Anatomic Relationships and Landmarks

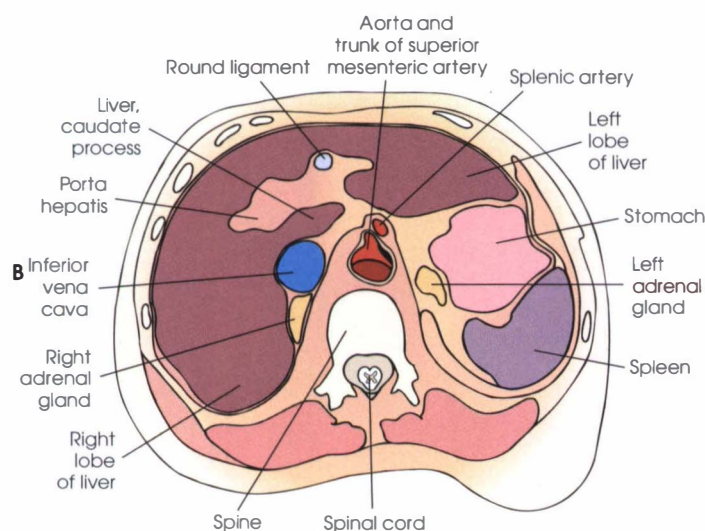
The ability of the sonographer to understand anatomy as it relates to the *sectional*, *coronal*, and *oblique planes* is critical to the performance of a high-quality sonogram (see Chapter 27 on Sectional Anatomy). Normal anatomy varies in size and position, and the sonographer must be able to demonstrate these findings on the sonogram. To complete this task, the sonographer must have a thorough understanding of anatomic relationships and their variations.

### Clinical Applications

#### ABDOMEN AND RETROPERITONEUM

The upper abdominal ultrasound examination generally includes a survey of the abdominal cavity from the diaphragm to the level of the umbilicus. Specific protocols are followed to image the texture, borders, anatomic relationships, and blood flow patterns within the liver, biliary system, pancreas, spleen, vascular structures, retroperitoneum, and kidneys. Patients may be examined in the supine, decubitus, upright, or prone positions.

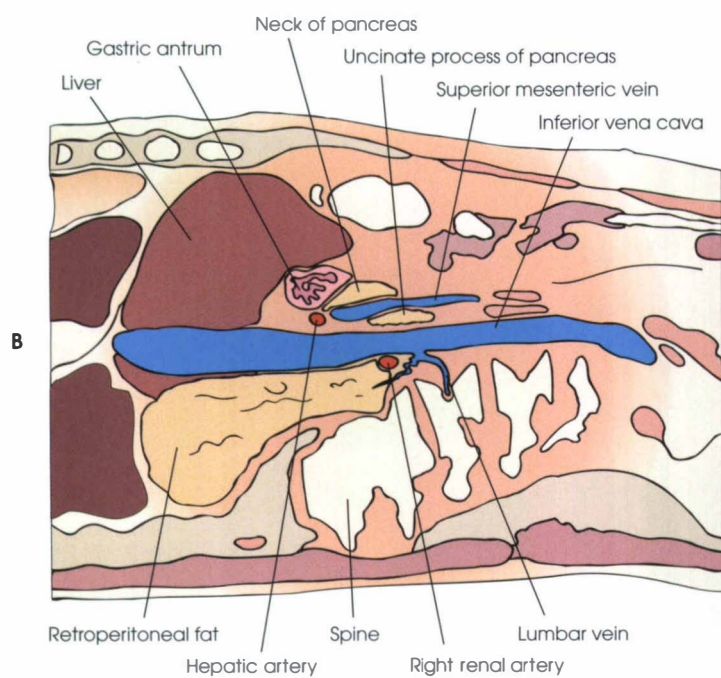
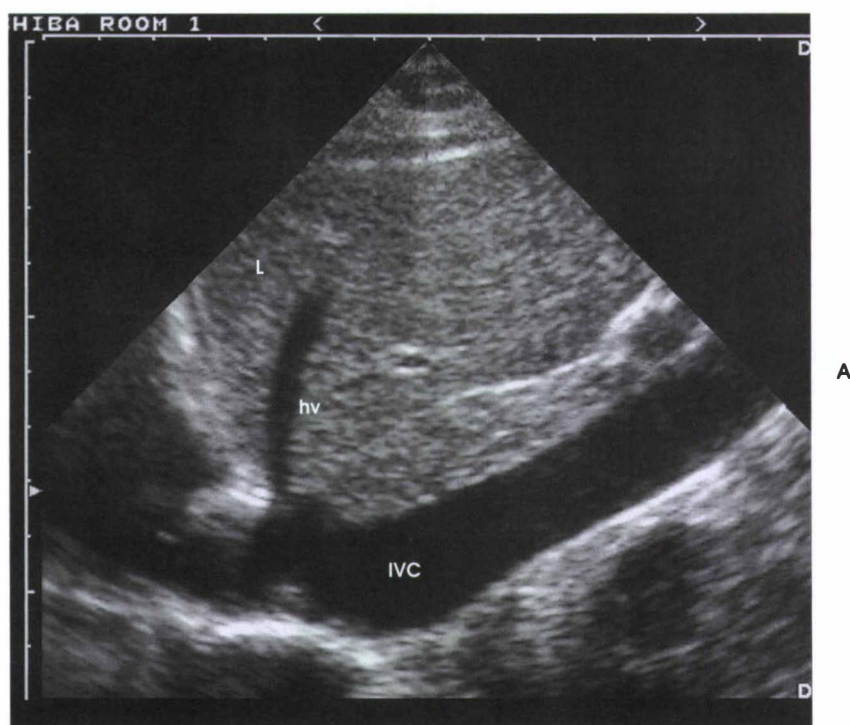




**Fig. 37-2** **A**, Transverse sonogram of the right upper quadrant over the right lobe of the liver. **B**, Line drawing of the gross anatomic section. **C**, Gross anatomic section at approximately the same level as **A**.

Air and gas in the abdominal cavity may obstruct the ultrasound beam. Consequently, the upper abdominal ultrasound examination is best performed after a patient has been fasting for at least 6 hours. Fasting also allows the gallbladder and bile duct to be distended for adequate visualization. Specific images of the abdominal cavity are obtained from the dome of the liver to the inferior border of the kidneys, with the vascular structures serving as the primary landmarks for the abdominal organs. Scanning is performed in the transverse, oblique, sagittal, coronal, and *subcostal* planes (Figs. 37-2 and 37-3).

The left upper quadrant may be obscured secondary to air in the stomach or gas in the overlying bowel, making it difficult to image the spleen, left kidney, tail of the pancreas, and suprarenal area. The patient position may be rotated to the decubitus position to provide a better "window" to image these structures or a liquid such as degassed water, tomato juice, or ultrasound contrast material may be given to dilate the stomach and fill the duodenum in an effort to improve visualization of the structures in the left upper quadrant.



**Fig. 37-3** **A**, Sagittal sonogram of the right upper quadrant over the medial segment of the left lobe of the liver (*L*), the hepatic vein (*hv*), and the inferior vena cava (*IVC*). **B**, Line drawing of the gross anatomic section. **C**, Gross anatomic section at approximately the same level as **A**.





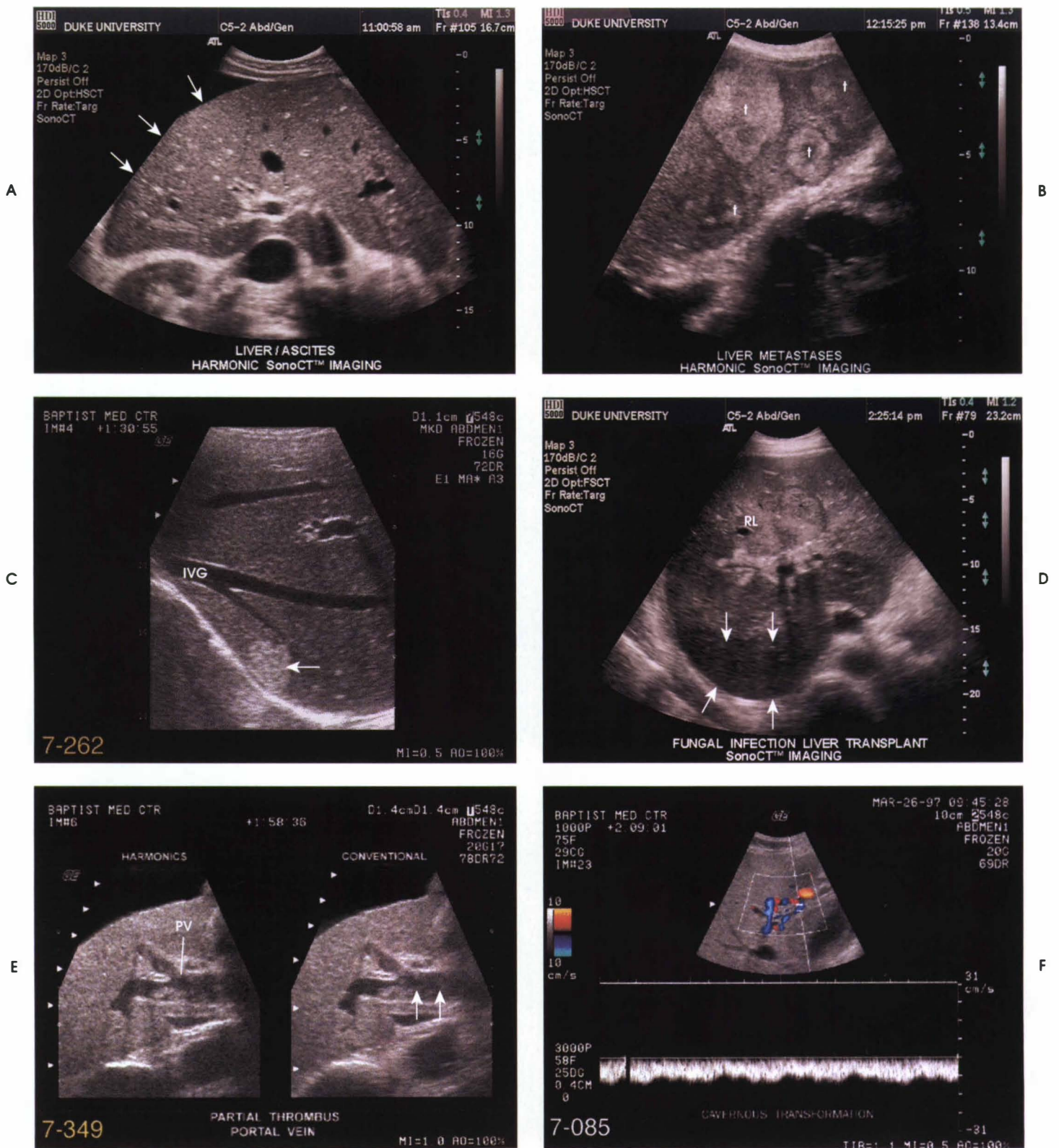
**Fig. 37-4** **A**, Normal transverse scan of the liver. Note the homogeneous liver texture with anechoic vascular structures representing the portal and hepatic veins and the inferior vena cava. **B**, Transverse scan of the middle hepatic vein as it empties into the inferior vena cava with spontaneous blood flow. **C**, Three-dimensional image of the hepatic vasculature.

The sonographer must have an understanding of the patient's clinical history and symptoms to produce an adequate survey of the abdominal cavity. The normal sonographic patterns of all the abdominal organs and vascular structures must be adequately imaged to detect any pathologic condition that may require further investigation. Although ultrasound cannot diagnose the specific pathology of a lesion, the clinical picture may lead to a more specific differential diagnosis to rule out infection, diffuse disease, hematoma, tumor, or an infiltrative process.

### Liver and spleen

The liver and spleen are evaluated to assess the size and homogeneity of the parenchymal tissues. The texture of these organs is normally uniform (*homogeneous*) throughout with the exception of the vascular structures that enter the hilus and branch into the surrounding tissue (Fig. 37-4). Abnormalities in this texture pattern enable the sonographer to determine if the organ has any of the following: fat infiltration, abscess, hematoma, cystic displacement, diffuse disease, or tumor invasion (Fig. 37-5). The presence or absence of vascular structures within the hepatosplenic organs helps the sonographer determine if portal hypertension, thrombosis, or diffuse disease is present. The combined use of color flow and Doppler helps to determine the direction of vascular flow or the presence of thrombus within the portal system or hepatic veins.

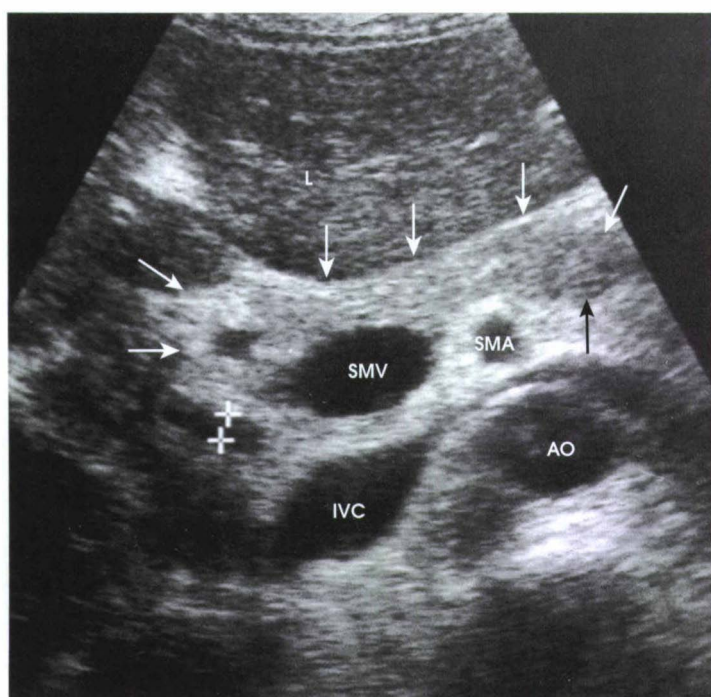




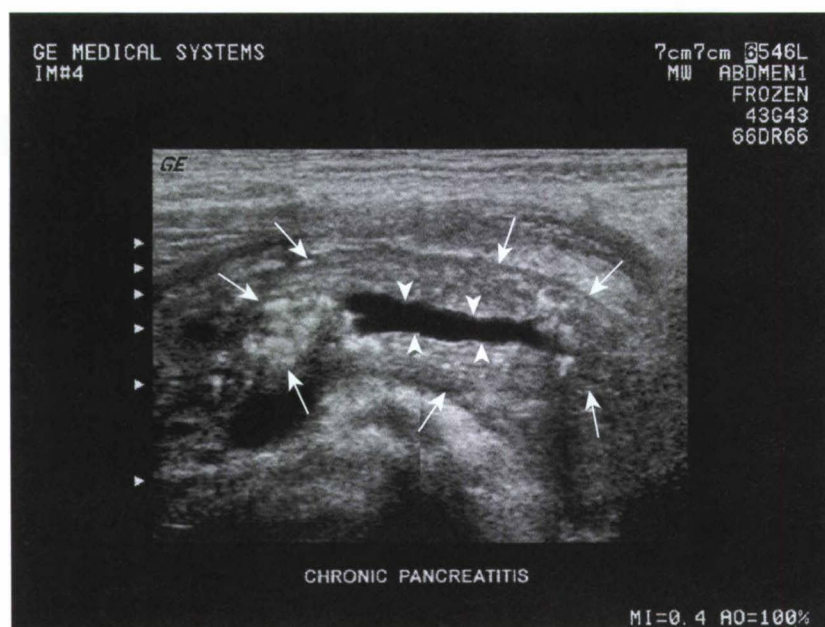
**Fig. 37-5** **A**, The liver parenchyma is outlined by ascitic fluid (arrows). **B**, Multiple hyper-echoic and "bull's-eye" tumors (*t*) within the liver represent metastatic disease. **C**, Sagittal image of the liver shows a bright echogenic tumor (arrow) posterior to the inferior vena cava (IVC). **D**, Inhomogeneity is shown along the posterior right lobe of the liver (RL) representing a fungal infection (arrows) in this liver transplant patient. **E**, Echoes within the prominent portal vein (PV) represent thrombus (arrows) secondary to portal hypertension. **F**, Portal hypertension may lead to cavernous transformation (arrows) of the portal veins.

### Pancreas

The pancreas is a retroperitoneal gland. Its head lies in the curve of the duodenum, and its body and tail lie posterior to the antrum of the stomach. The texture of the pancreas varies, depending on the amount of fat that is interspersed throughout its islets of Langerhans. The aorta, inferior vena cava, superior mesenteric artery, and vein serve as the posterior landmarks for the pancreas (Fig. 37-6). Ultrasound examination of the pancreas can demonstrate inflammation (acute or chronic), tumor, abscess, or retroperitoneal bleed (Figs. 37-7).

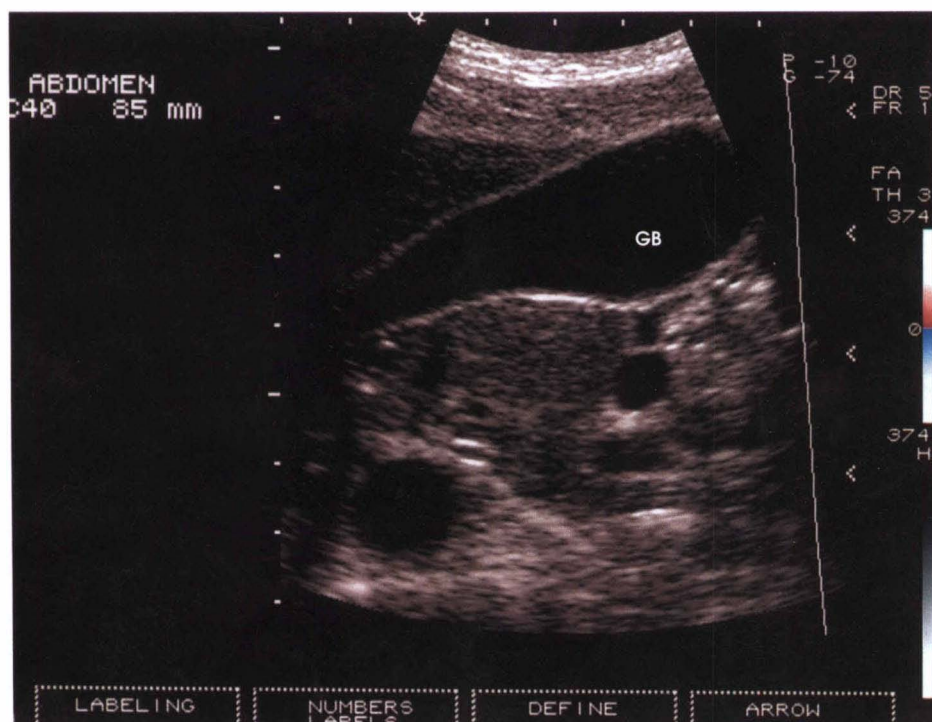


**Fig. 37-6** Transverse scan over the epigastric region of the abdomen demonstrating a normal pancreas (arrows). The left lobe of the liver (L) is seen anterior to the pancreas. The aorta (AO), and inferior vena cava (IVC), superior mesenteric artery (SMA), and superior mesenteric vein (SMV), are the posterior borders.



**Fig. 37-7** Transverse scan over the pancreas area showing bright, echogenic reflections (arrows) that represent chronic, fibrotic pancreatitis. The dilated pancreatic duct is seen (arrowheads).

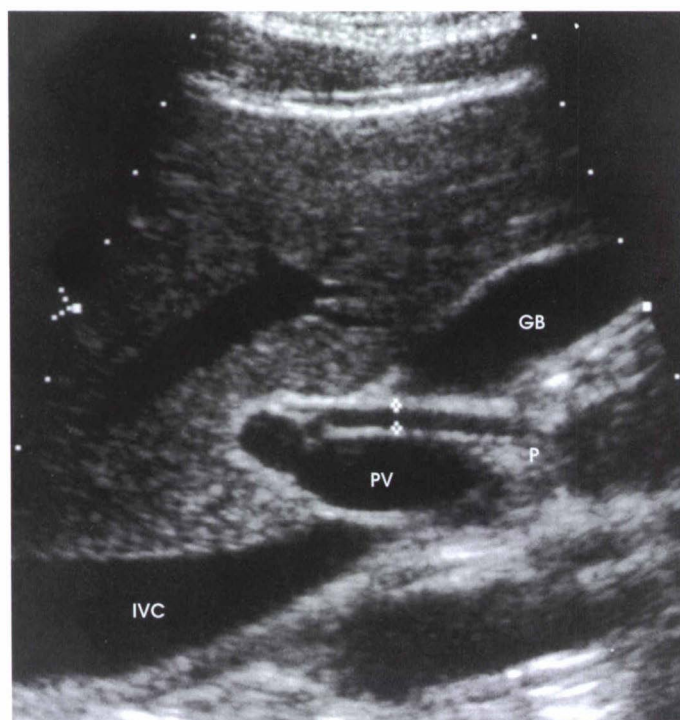




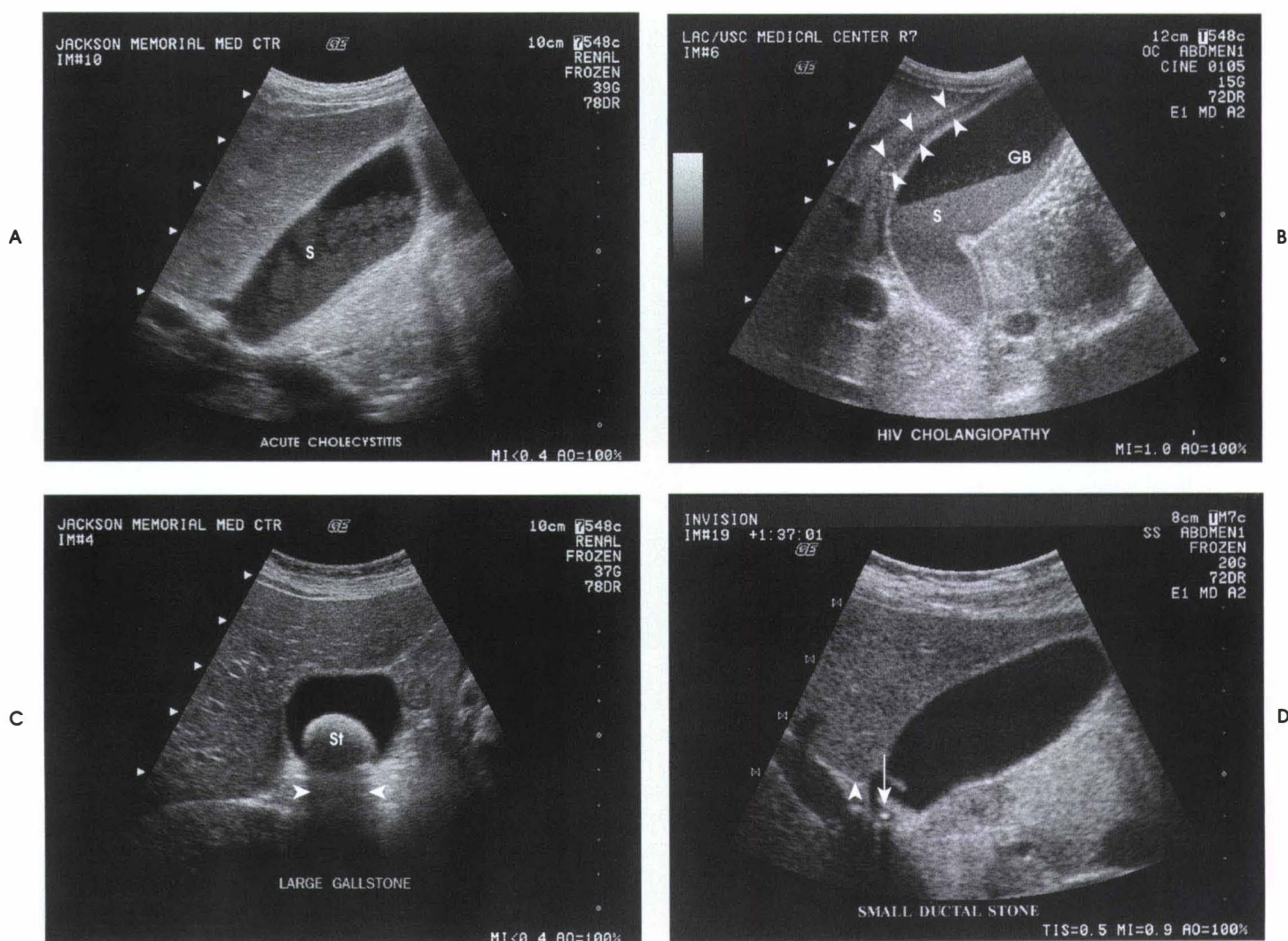
**Fig. 37-8** Sagittal scan over the right upper quadrant showing a well-distended gallbladder (GB) with thin walls.

### Biliary system

On ultrasound examination the gallbladder and bile ducts are seen just inferior to the right lobe of the liver and anterior to the right kidney (Fig. 37-8). The intrahepatic bile duct runs slightly anterior to the portal vein as it drains bile from the liver into the storage cistern (gallbladder) via the cystic duct (Fig. 37-9). Bile is released into the common bile duct, where it joins the pancreatic duct secretions to drain into the duodenum at a small raised area called the duodenal papilla. The biliary system is evaluated with ultrasound to assess size and wall thickness and to detect sludge, stones, polyps, or other masses (Fig. 37-10).



**Fig. 37-9** The common bile duct (denoted by + calipers) may be seen as it rests anterior to the portal vein (PV), before it enters the posterior border of the pancreas (P). IVC, inferior vena cava; GB, gallbladder.



**Fig. 37-10** **A**, Longitudinal scan of the enlarged gallbladder filled with echogenic sludge (s). The wall of the gallbladder is thickened secondary to acute cholecystitis (arrows). **B**, A patient with HIV shows a distended gallbladder (GB) with echogenic sludge (s) representing cholangiopathy. **C**, The large gallstone (st) within the gallbladder is echogenic with an acoustic shadow posterior (arrowheads). **D**, This prominent gallbladder is distended because of a small echogenic stone (arrow) lodged in the distal cystic duct (arrowhead).



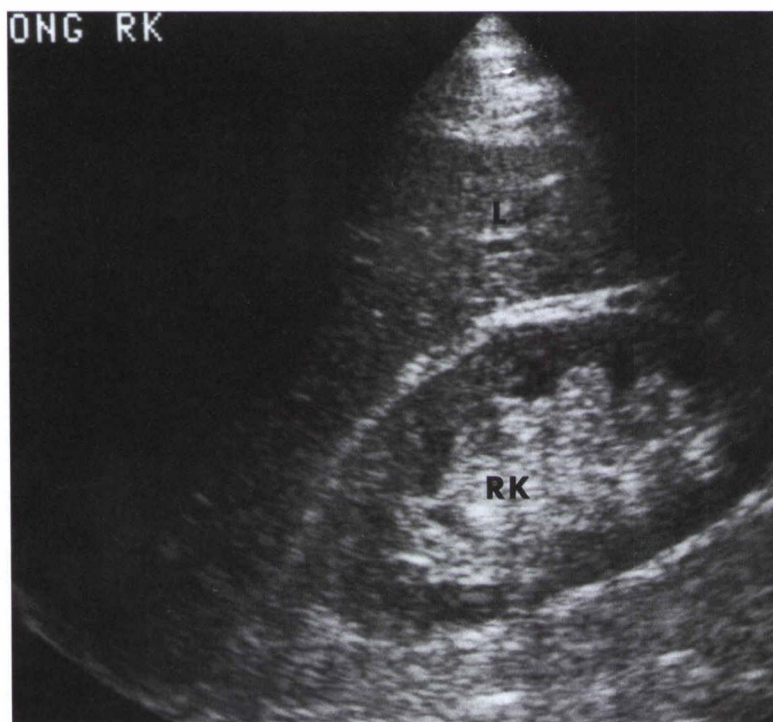


Fig. 37-11 Sagittal scan of the right kidney (*RK*), as it lies posterior to the inferior border of the right lobe of the liver (*L*).

### Kidneys

The kidneys rest on the posterior surface of the abdominal cavity in an oblique plane lateral to the psoas muscles (Fig. 37-11). The large right lobe of the liver causes the right kidney to be slightly lower than the left kidney. The renal vascularity may be imaged with color Doppler as the patient is rolled into a slight decubitus position (Fig. 37-12). The kidneys are assessed for size, dilation of calyces structures (hydronephrosis), or abnormal texture pattern secondary to a cyst, a tumor, an abscess, an infarct, a hematoma, or an infiltrative process (Figs. 37-13 and 37-14). Ultrasound is also useful for denoting the exact location and depth of the lower pole of the kidney; the urologist can then use this information in performing a renal biopsy. The transplanted kidney is placed in the iliac fossa, just superficial to the muscle layer. Ultrasound is very useful in measuring the size of the transplanted kidney, imaging the organ's texture to detect abnormal patterns that may suggest rejection, or evaluating the transplant recipient for hydronephrosis. Fluid collections (i.e., lymphocele, seroma, abscess, hematoma) that surround the renal transplant may also be evaluated with ultrasound. The anterior and posterior pararenal spaces may be evaluated for the presence of abnormal fluid or ascites, hematoma, or tumor invasion.

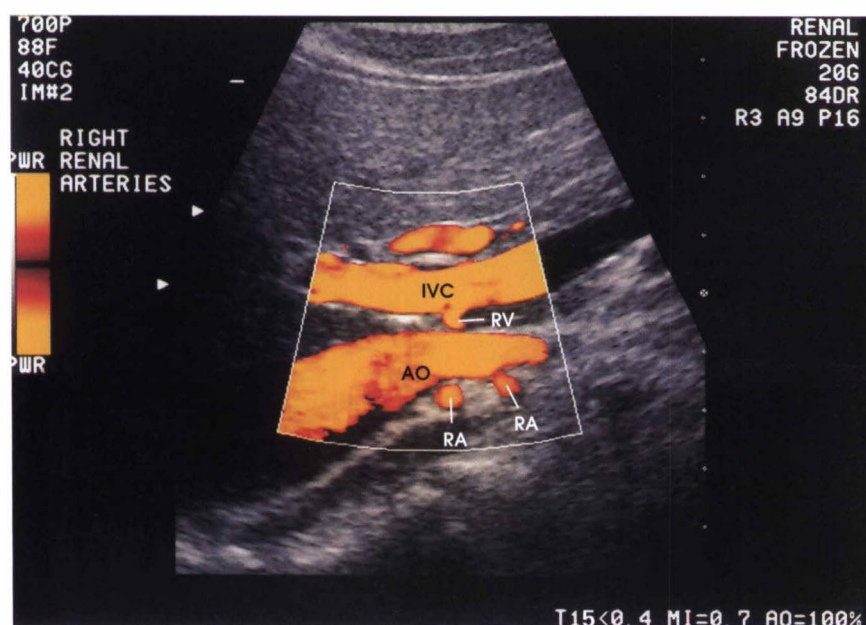
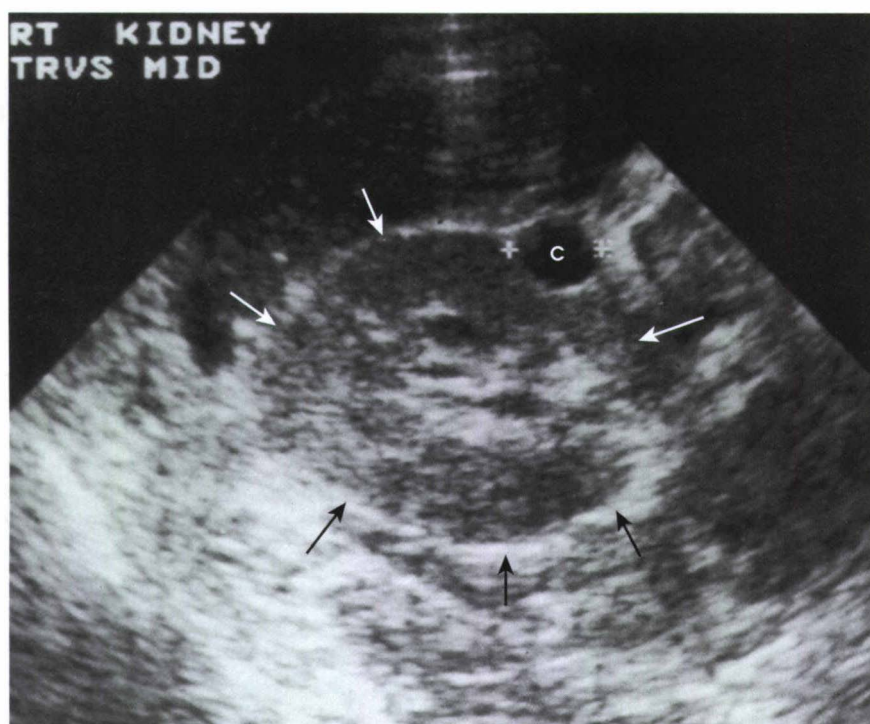


Fig. 37-12 The patient is rolled into a left decubitus position to show the color Doppler image of the inferior vena cava (*IVC*) and renal veins (*RV*) anterior to the aorta (*A*) and duplicated right renal arteries (*RA*).

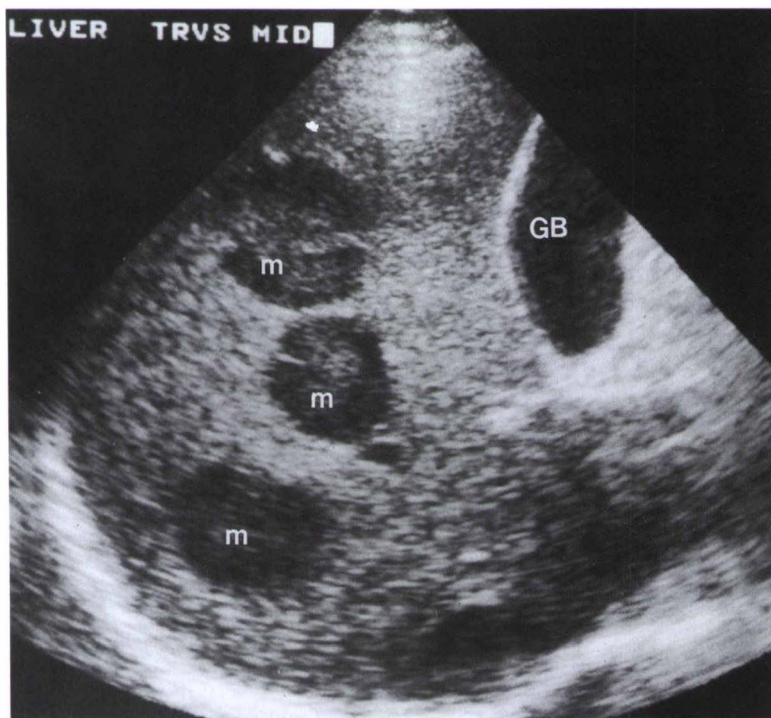




**Fig. 37-13** Transverse scan of the right kidney (arrows) with a small renal cyst (c) located on the outer margin of the renal parenchyma (denoted by calipers).



**Fig. 37-14** In hydronephrosis of the kidney the dilated pyelocaliceal system appears as a separation of the renal sinus echoes by fluid-filled areas that conform anatomically to the infundibula, calyces (c), and pelvis (p).



**Fig. 37-15** Transverse scan of the right lobe of the liver showing multiple hypoechoic areas with a central-core echo pattern suggestive of metastatic disease (*m*) from adenocarcinoma of the colon. The gallbladder (*GB*) is shown along the upper right border.

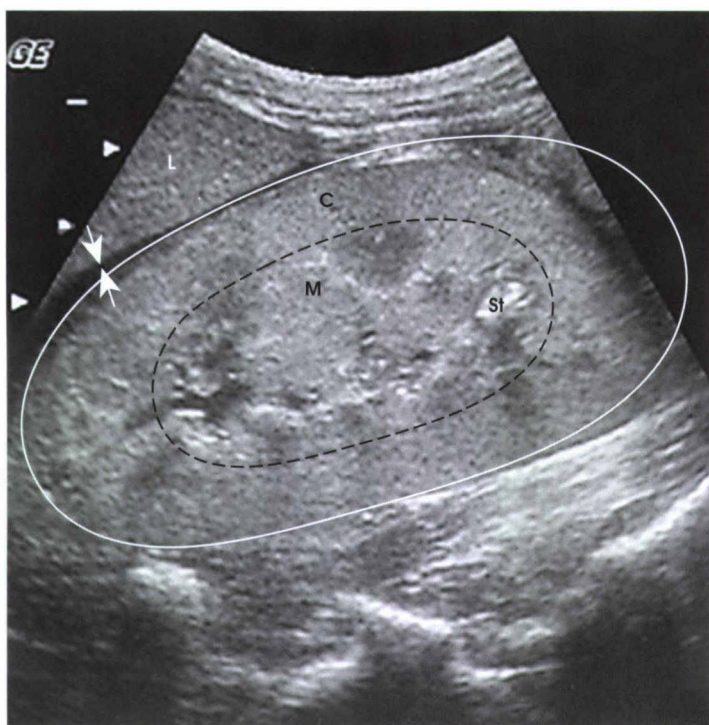
### Characteristics of the sonographic image

The sonographer must be able to analyze a mass to determine if its borders are smooth, irregular, poorly defined, thin, or thick to further define its characteristics. Once a mass is suspected, the sonographer must evaluate its acoustic properties to determine if it is *heterogeneous*, *homogeneous*, *hypoechoic*, *hyperechoic*, *isoechoic*, or *anechoic*. A hypoechoic lesion is characterized by very low-level echoes with a good posterior border (Fig. 37-15). A hyperechoic mass may represent a tumor, thrombus, or calcification; the lesion presents with bright *echo* reflectors and possibly shadowing beyond it (Fig. 37-16). An isoechoic mass shows nearly the same texture pattern as the surrounding parenchyma with no significant change in the through transmission (Fig. 37-17). An anechoic mass shows no internal echoes, has smooth walls, and displays increased through transmission (Fig. 37-18).

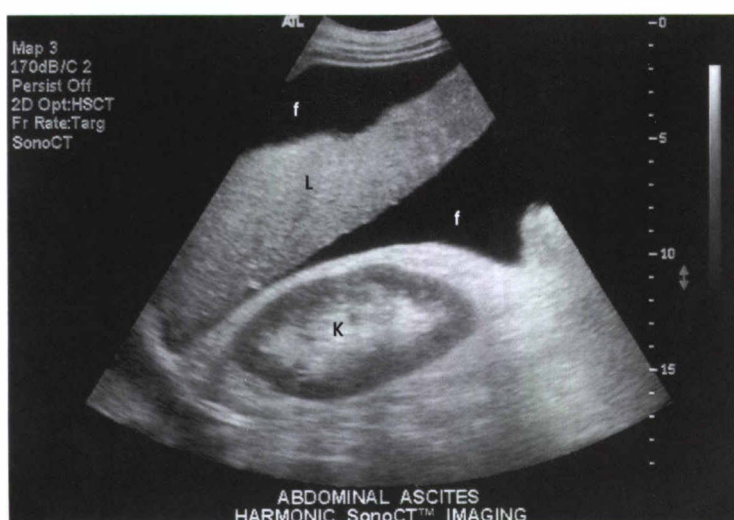


**Fig. 37-16** Sagittal scan of the right upper quadrant showing the liver (*L*) and the anechoic gallbladder with a large echogenic focus (gallstone, *sf*) causing a large acoustic shadow posterior to its border (*arrows*).





**Fig. 37-17** Sagittal image of the echogenic kidney as compared to the liver parenchyma (L). A small amount of ascites in Morison's pouch (arrows) separates the inferior border of the liver from the anterior border of the kidney. The renal cortex (c) and medulla (m) are isoechoic to one another without a distinguishable border. A small echogenic renal stone (St) is found in the lower pole with an acoustic shadow posterior.

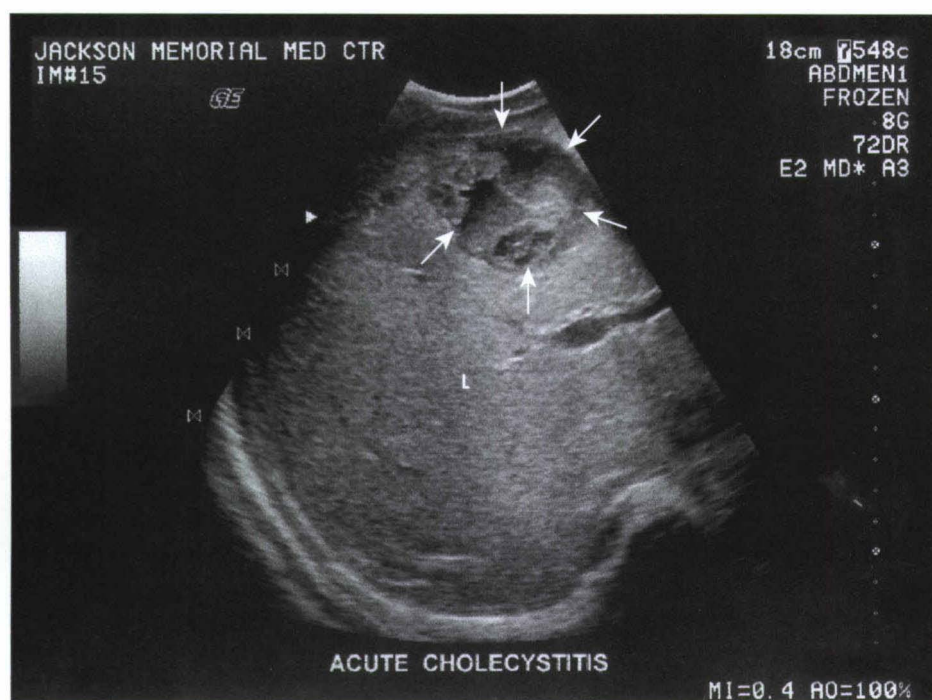


**Fig. 37-18** Sagittal image of the cirrhotic liver (L) surrounded by anechoic ascitic fluid (f). The right kidney is well seen posterior to the liver (K).

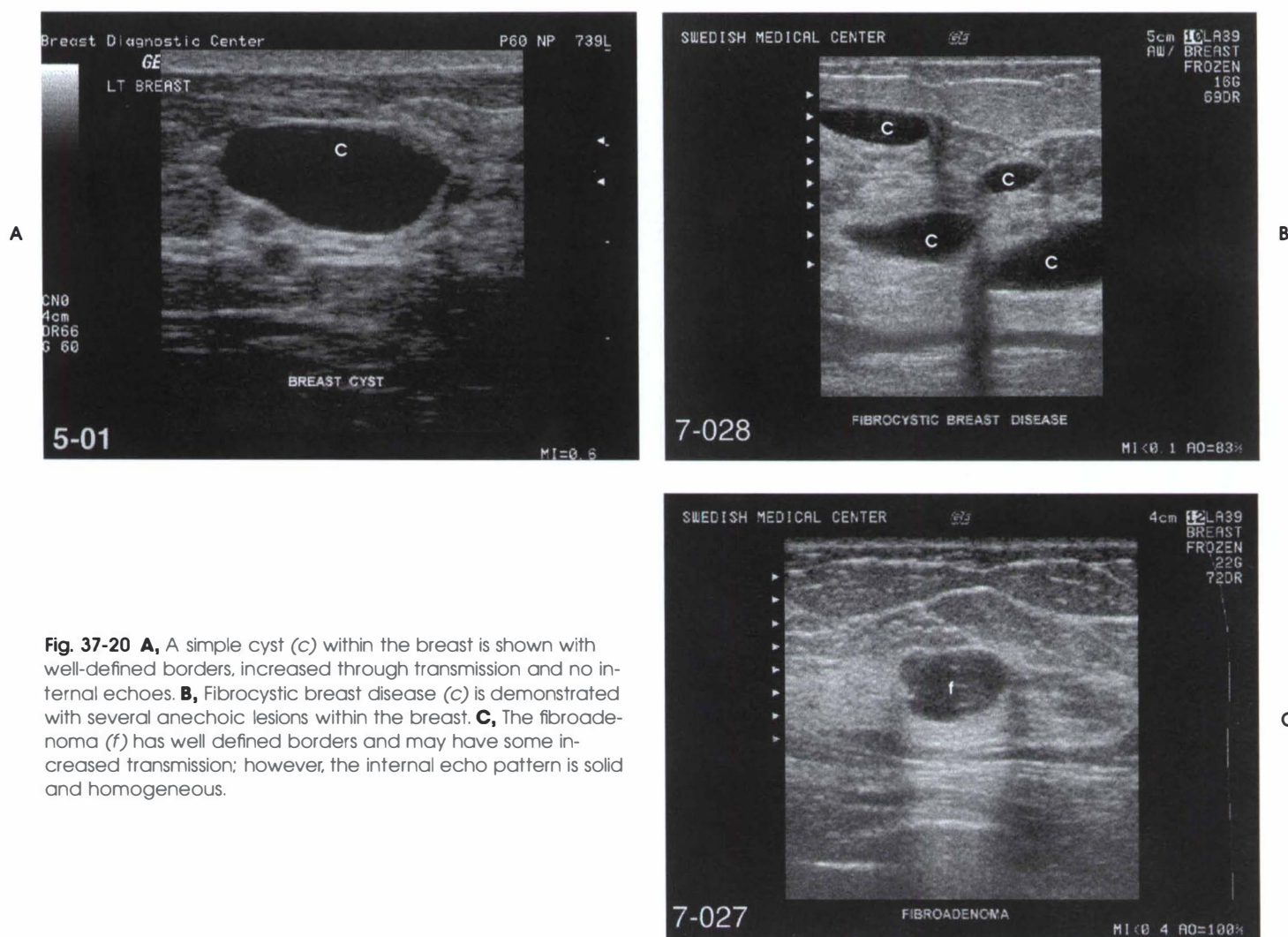


A mass that shows characteristics of more than one pattern is considered complex. Examples include an abscess, a necrotic tumor with hemorrhage, a decomposing thrombus, a cyst with septations, or an abscess (Fig. 37-19).

Once a mass has been localized, ultrasound may aid the clinician in the aspiration or biopsy procedure. The sonographer may locate the site of the lesion, calculate its depth, and determine the direction and angulation of needle placement for the procedure.



**Fig. 37-19** Transverse scan of a patient with acute cholecystic disease shows a complex mass in the area (arrows) of the gallbladder. L, Liver.

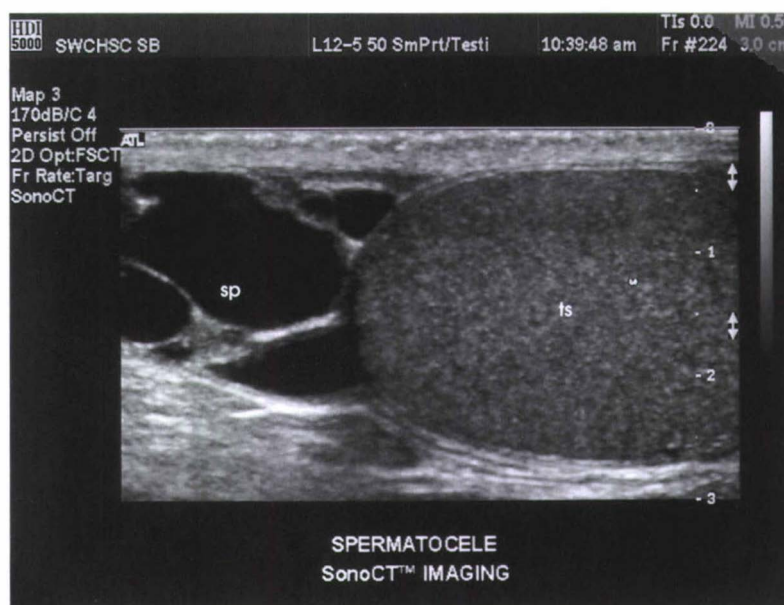


**Fig. 37-20** **A**, A simple cyst (c) within the breast is shown with well-defined borders, increased through transmission and no internal echoes. **B**, Fibrocystic breast disease (c) is demonstrated with several anechoic lesions within the breast. **C**, The fibroadenoma (f) has well defined borders and may have some increased transmission; however, the internal echo pattern is solid and homogeneous.

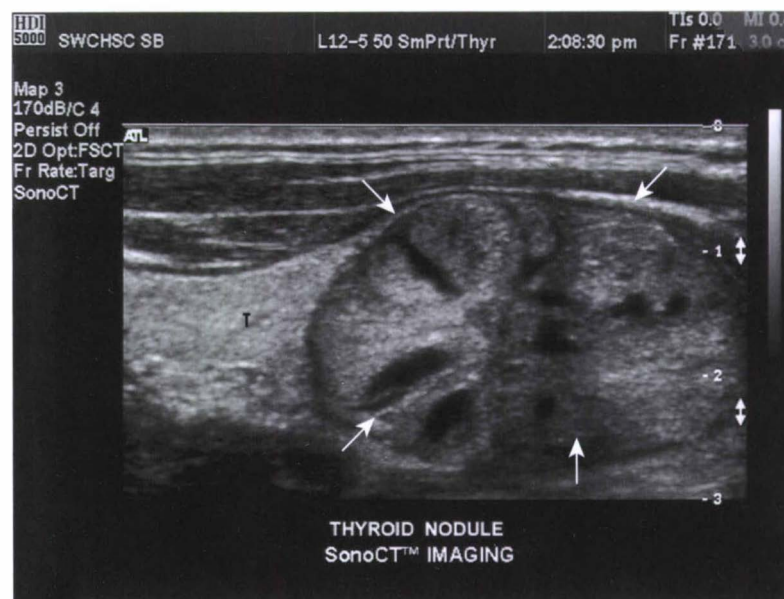


## SUPERFICIAL STRUCTURES

Superficial structures such as the thyroid, breast, scrotum, and penis are imaged very well with ultrasound using high-frequency transducers. Routine ultrasound examination demonstrates minute structures such as the lactiferous ducts within the breast and the spermatic cord within the testes. In conjunction with mammography, ultrasound is able to characterize the texture of a breast mass to determine if the mass is fluid-filled, complex, or solid (Fig. 37-20). Pathologic hypoechoic and hyperechoic areas within the scrotal structures (e.g., cyst, spermatocele, carcinoma, hydrocele, torsion) may be demonstrated with high-resolution ultrasound instrumentation (Fig. 37-21). Realtime evaluation of the thyroid gland may demonstrate enlargement with inhomogeneous texture (goiter), a solid mass with a halo surrounding its border (adenoma), or a solid mass with poorly defined borders (carcinoma) (Fig. 37-22).



**Fig. 37-21** Longitudinal scan of the scrotum shows the homogeneous testis (*ts*) with a complex echo pattern superior to the testes that represents a spermatocele (*sp*).

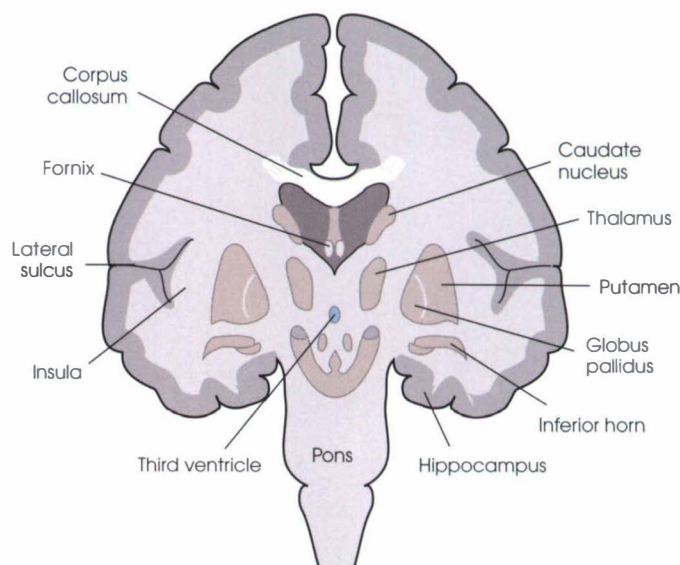


**Fig. 37-22** A large complex-solid mass (arrows) is shown within the thyroid gland (*T*).

## NEONATAL NEUROSONOGRAPHY

The premature infant is susceptible to intracranial hemorrhage during the stress of delivery and the struggle to survive. The internal anatomy of the neonatal brain may be well imaged through the coronal suture with high-frequency ultrasound. Structures such as the ventricular system, septum pellucidum, corpus callosum, choroid plexus, posterior fossa, vermis, and cerebrum are visualized with detailed resolution (Fig. 37-23). The infant may be examined in the special-care nursery using special petite transducers that adapt to the neonatal skull.

Sonography is the preferred clinical diagnostic tool to evaluate the premature infant for intracranial hemorrhage, infection, or shunt drainage for ventriculomegaly (Fig. 37-24). Other pathologic conditions that ultrasound examination can detect within the neonatal skull include meningo-myelocele, Arnold-Chiari deformity, hydrocephalus or ventriculomegaly, Dandy-Walker deformity, agenesis of the corpus callosum, and arteriovenous malformation.



**Fig. 37-23** Coronal line drawing of the neonatal head shows the development of the corpus callosum, ventricular system, thalamus, and pons.

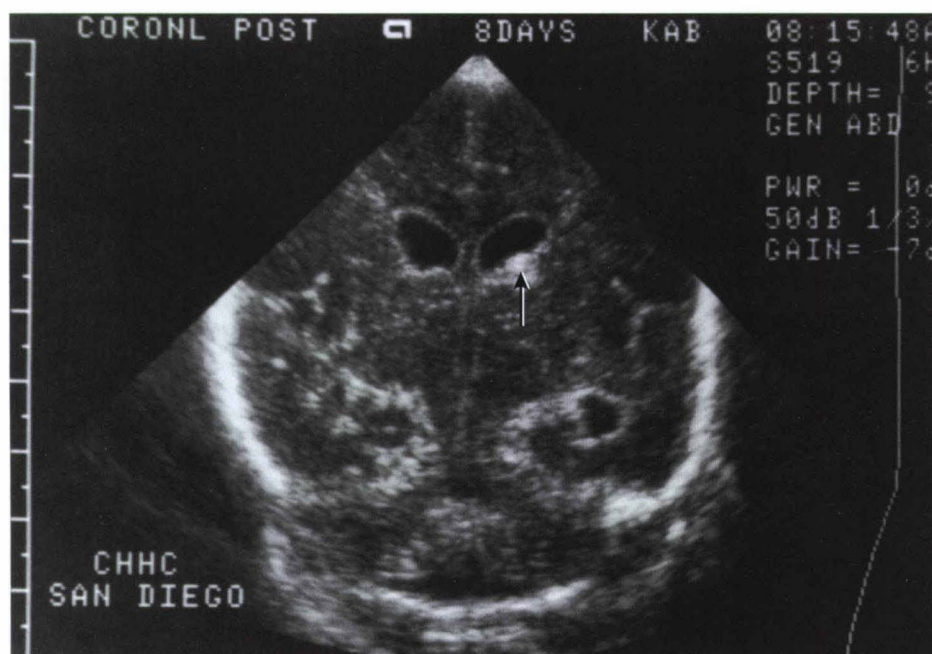


Fig. 37-24 Posterior coronal image of an 8-day-old premature infant with a bilateral grade III bleed. The ventricles are slightly dilated, and a subependymal bleed (arrow) extends into the ventricular cavity.



## GYNECOLOGIC APPLICATIONS

### Anatomic features of the pelvis

The pelvis is divided into the greater and lesser pelvic cavity, with the pelvic brim being the circumference of a plane dividing the two cavities. The greater pelvic cavity, or “false” pelvis, is superior to the pelvic brim and is bounded on each side by the ileum. The lesser pelvic cavity, or “true” pelvis, is caudal to the pelvic brim. The walls of the pelvic cavity are formed by several muscles collectively called the pelvic diaphragm. These muscles include the levator ani, piriformis, and coccygeus muscles.

The female peritoneal cavity extends inferiorly into the lesser pelvis and is bounded by the peritoneum, which covers the rectum, bladder, and uterus. In the female, the peritoneum descends from the anterior abdominal wall to the level of the pubic bone onto the superior surface of the bladder (Fig. 37-25). It then passes from the bladder to the uterus to form the vesicouterine pouch. The rectouterine pouch, or pouch of Douglas, lies between the uterus and the rectum. Free fluid accumulates in this area before it moves cephalad to fill the gutters of the abdominal cavity.

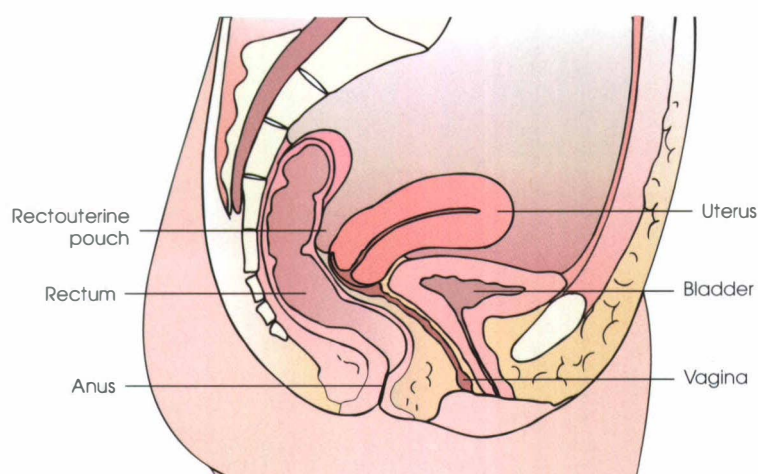
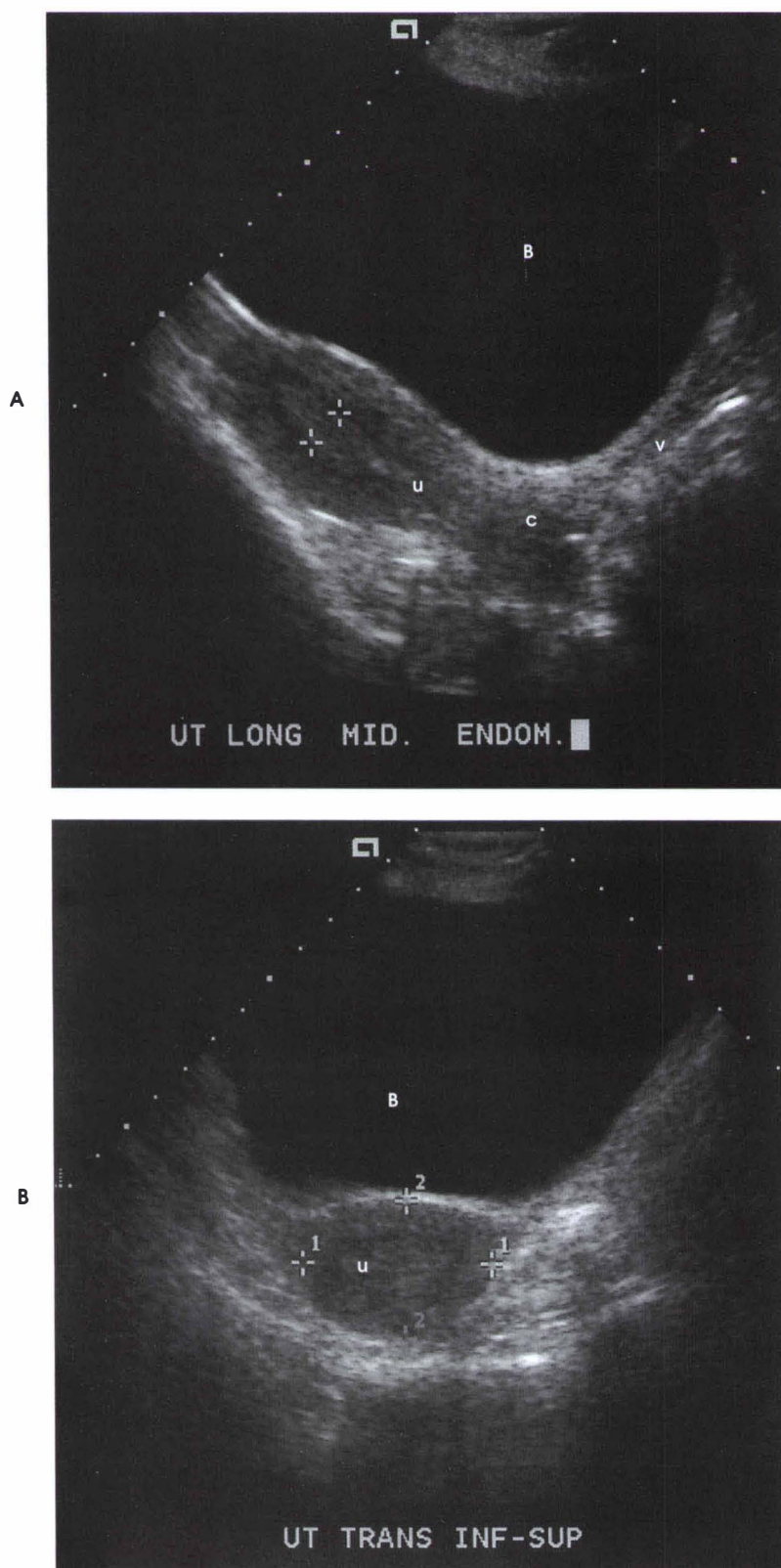


Fig. 37-25 Sagittal line drawing of the female pelvis.



**Fig. 37-26 A,** Normal sagittal sonogram of the midline of the pelvic cavity. The distended urinary bladder (*B*) is shown anterior to the uterus (*u*). The endometrium appears as the bright linear echo within the uterus (*crossbars*). The myometrium is the homogeneous smooth echo tissue surrounding the endometrium of the uterus. The cervix (*c*) and vagina (*v*) are well seen. **B,** Transverse image of the distended urinary bladder anterior to the uterus (*crossbars*).

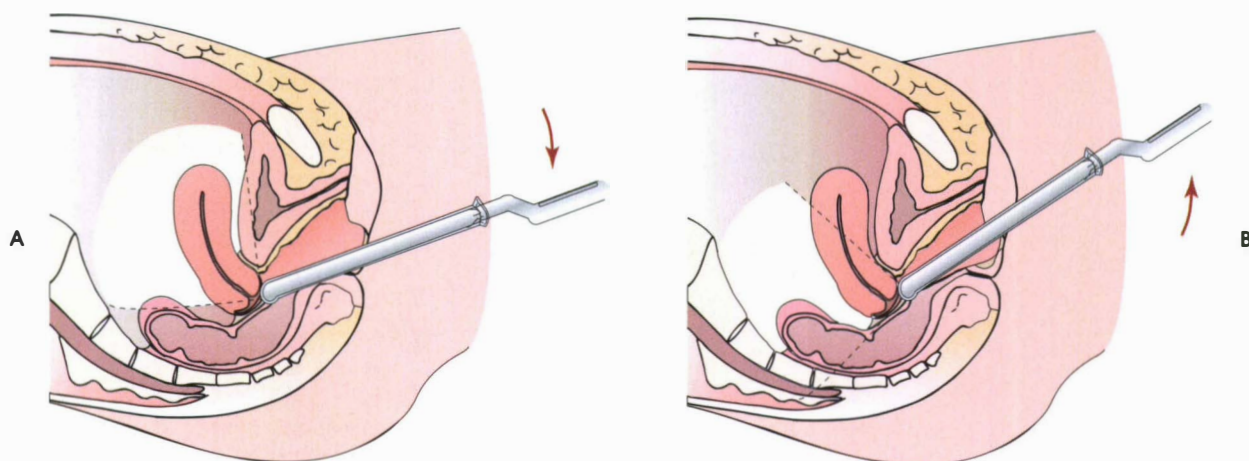
### Sonography of the female pelvis

A complete transabdominal examination of the female pelvis includes visualization of the distended urinary bladder, uterus, cervix, endometrial canal, vagina, ovaries, and supporting pelvic musculature. The full bladder helps to push the small bowel superiorly out of the pelvic cavity, flattens the body of the uterus, and serves as a *sonic window* to image the pelvic structures (Fig. 37-26). The rectum and other bowel structures may also be seen and must be distinguished from the normal pelvic structures. The sonographer may distinguish the bowel by watching for peristalsis or changes in fluid patterns throughout the examination. The fallopian tubes and broad ligaments are usually seen only when the patient presents with excessive free fluid or ascites within the pelvic cavity.

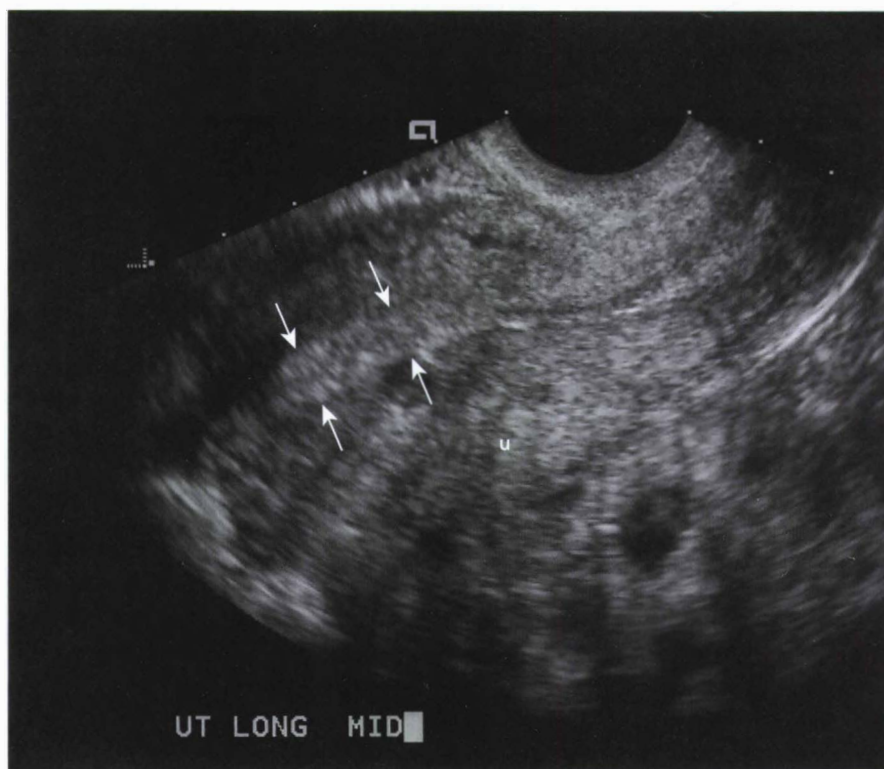
*Endovaginal* ultrasound has now become the preferred procedure for imaging the endometrium, myometrium, and ovaries. A high-frequency transducer is inserted into the vagina to image the uterus, cervix, fallopian tubes, ovaries, and adnexal area in coronal and sagittal planes (Fig. 37-27).

Sonography of the pelvis is clinically useful for imaging normal anatomy, identifying the size of ovarian follicles as part of an infertility workup, measuring endometrial thickness, evaluating the texture of the myometrium, determining if a pregnancy is intrauterine or extrauterine, detecting tumors or abscess formations, and localizing an intrauterine contraceptive device (Fig. 37-28).





**Fig. 37-27** **A**, Transvaginal sagittal scan with anterior angulation to better visualize the fundus of a normal anteverted uterus. **B**, Transvaginal sagittal scan with posterior angulation to better visualize the cervix and rectouterine recess.



**Fig. 37-28** Transvaginal midline sagittal image of the uterus. The endometrium is seen as an echogenic line (arrows) in the central part of the uterus (u). The endometrium thickens after ovulation occurs.

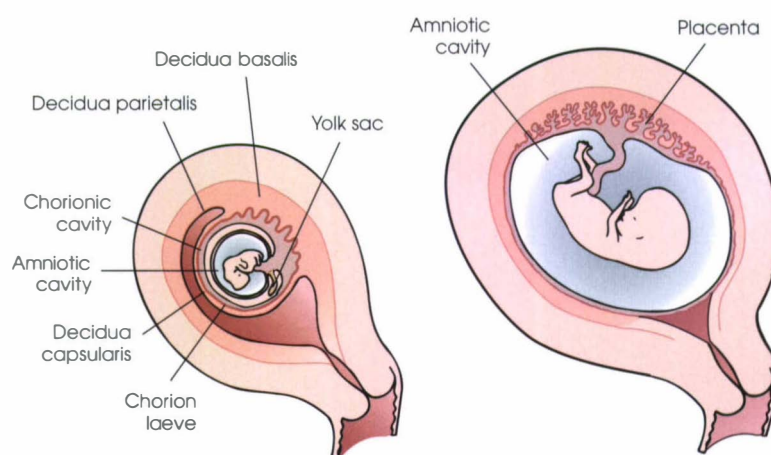
Distinct echo patterns of an enlarged uterus allow the sonographer to distinguish a leiomyoma from endometriosis or from a gestational sac. The sonographer is able to identify the characteristic patterns of a pelvic mass to distinguish if it is cystic, solid, or complex. The ultrasound interpretation, correlated with the patient's history and clinical symptoms, helps to provide a differential diagnosis for the clinician.

Sonography of the follicles within the ovary has been used to follow infertile women to monitor the correct time to receive fertility medication. A large follicular cyst may be an indication that the egg is ready for stimulation with high doses of human chorionic gonadotropin (hCG) and subsequent fertilization.

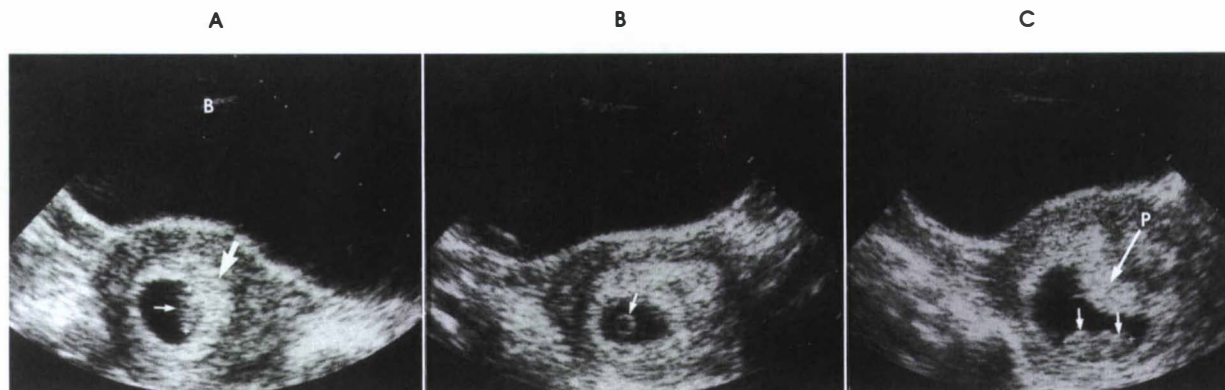
In postoperative patients with a fever of unknown origin, sonography may play a role in excluding abscess formation that may form in the cul-de-sac, the peripheral margins, or the gutters of the abdomen or perirenal space.

## OBSTETRIC APPLICATIONS

The pregnant woman is the ideal candidate for an ultrasound examination. The amniotic fluid enhances the sound penetration to differentiate fetal anatomy, umbilical cord, placenta, and amniotic membranes within the uterine cavity. *Endovaginal ultrasound* is the procedure of choice during the first trimester of pregnancy to delineate the gestational sac with the embryo, yolk sac, chorion, and amniotic cavities. The gestational sac may be visualized as early as 4 weeks from the date of conception with endovaginal ultrasound (Figs. 37-29 and 37-30). The embryo, heartbeat, and site of the placenta may be seen at 5 weeks of gestation.



**Fig. 37-29** First trimester representation of the developing embryo and yolk sac within the amniotic and chorionic cavities of the uterus.



**Fig. 37-30** **A**, Transabdominal sonograms of the first trimester pregnancy demonstrating the distended urinary bladder (**B**), gestational sac (*large arrow*), and embryo (*small arrow*). **B**, Small yolk sac (*small arrow*). **C**, Beginning of the placenta (**P**) and embryo (*small arrows*).





Fig. 37-31 Three-dimensional reconstruction of the fetal face.

The beginning of the second trimester (13 to 28 weeks of gestation) allows the sonographer to image the detailed anatomy of the fetus (Fig. 37-31). Structures such as the brain, face, limbs, neck, abdominal wall, liver, gallbladder, kidneys, stomach, pancreas, bowel, heart, lungs, and bladder may be seen with high-resolution transducers (Fig. 37-32). Heart motion, fetal size and position, and number of fetuses may be easily assessed with sonography. Serial examinations provide information relevant to normal or abnormal growth of the fetus and placenta.

The location and homogeneity of the placenta may be accurately defined in a patient who, presenting with clinical signs of pain and bleeding, may be diagnosed with placenta previa or abruptio placentae. With ultrasound the lower extent of the placenta may be seen in relation to the cervical os to determine if placenta previa is present. The sonographer may provide support to the perinatologist by helping localize the position of the placenta and fetus in amniocentesis, chorionic villus sampling, fetal blood sampling, or cord transfusion procedures. Color flow Doppler has been useful in defining the vascularity of the placenta in difficult cases such as placenta previa or placenta accreta. Color Doppler is also useful to evaluate the umbilical cord for the number of vessels, the twist of the cord, the length, thickness, or other abnormalities (Figs. 37-33 and 37-34).

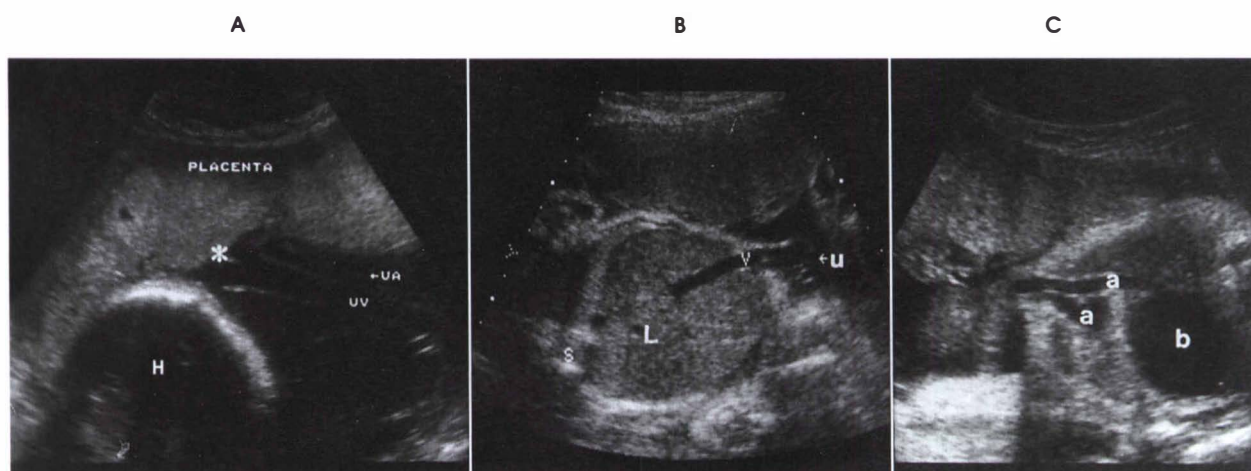
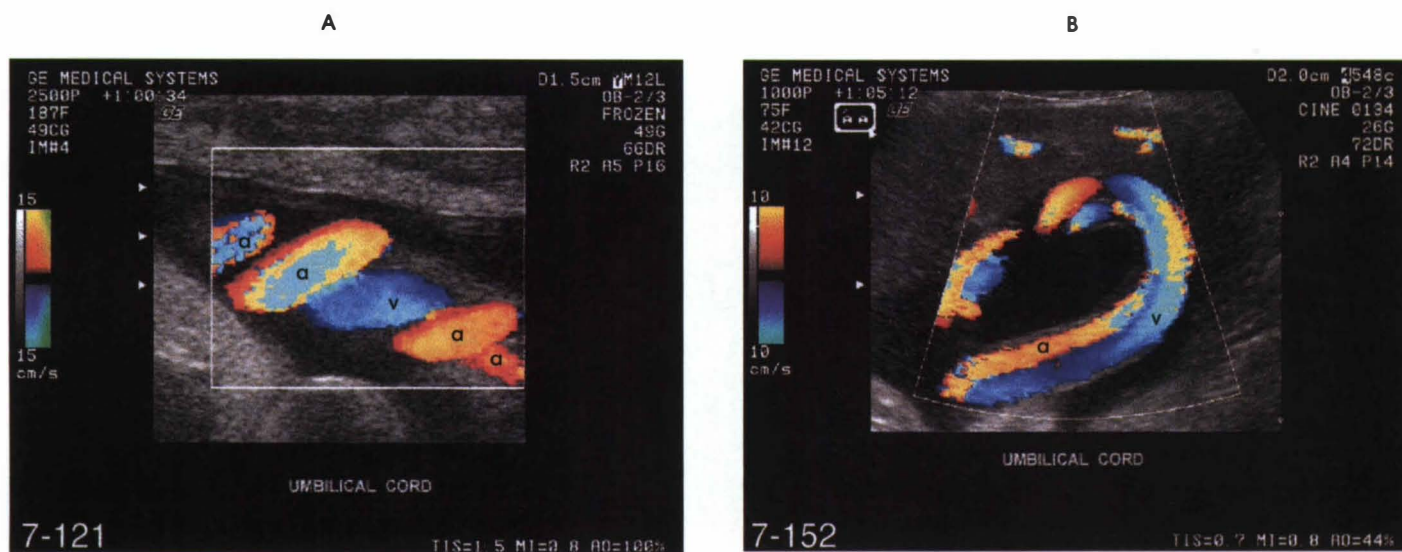


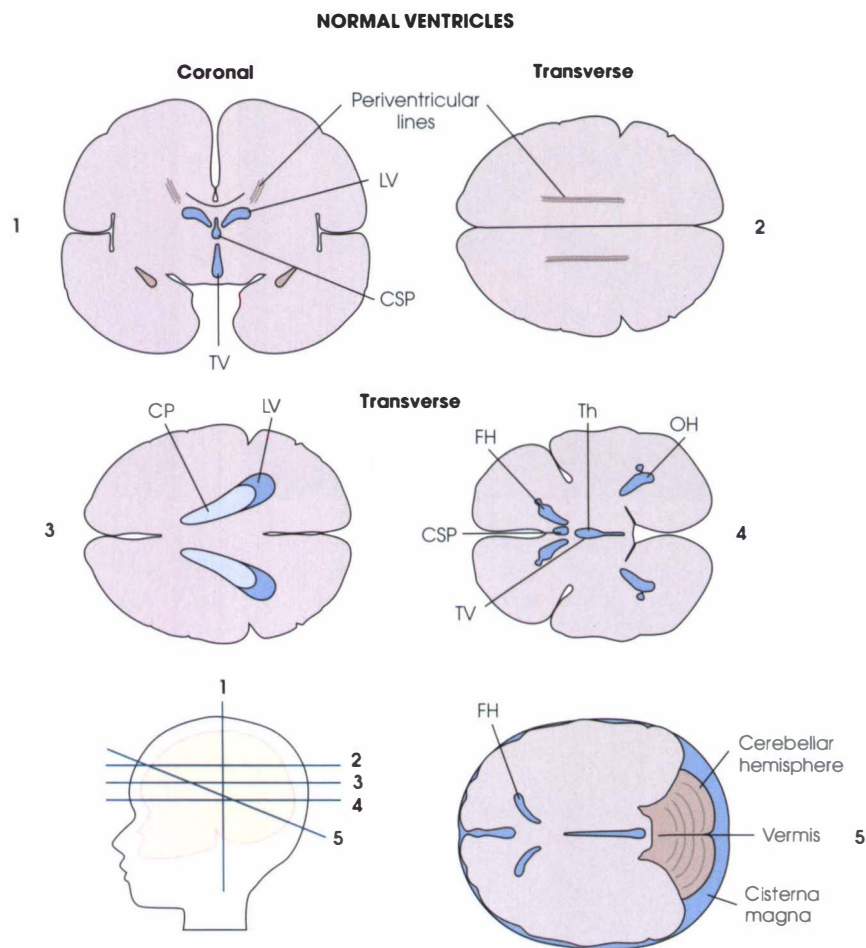
Fig. 37-32 **A**, The placenta is anterior to the fetal head (H) with the umbilical cord (UA). Umbilical arteries: UV, umbilical vein). **B**, The fetal abdomen at the level of the liver (L), umbilical vein (V), and cord insertion (U). **C**, Cross section of the fetal pelvis at the level of the bladder (b) and hypogastric arteries (a).



**Fig. 37-33 A**, Color Doppler demonstrates the normal umbilical cord (c) with two arteries (red) and one vein (blue) in a left-ward twist. The color flow within the artery shows helical flow patterns of blue/yellow/red). **B**, Color Doppler demonstrates a two vessel cord with the absence of one umbilical artery and no twist.



**Fig. 37-34** Color Doppler demonstrates the cord (c) wrapped around the fetal neck (N) is referred to as a nuchal cord.

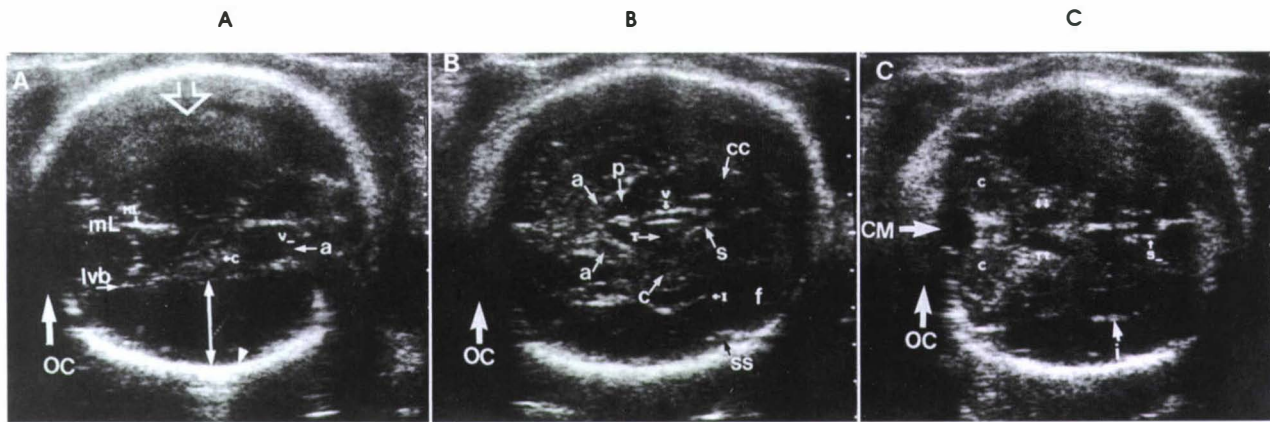


**Fig. 37-35** Schematic of the normal fetal head: LV, Lateral ventricle; CSP, cavum septum pellucidum; TV, third ventricle; CP, choroid plexus; FH, frontal horn; Th, thalamus; OH, occipital horn.



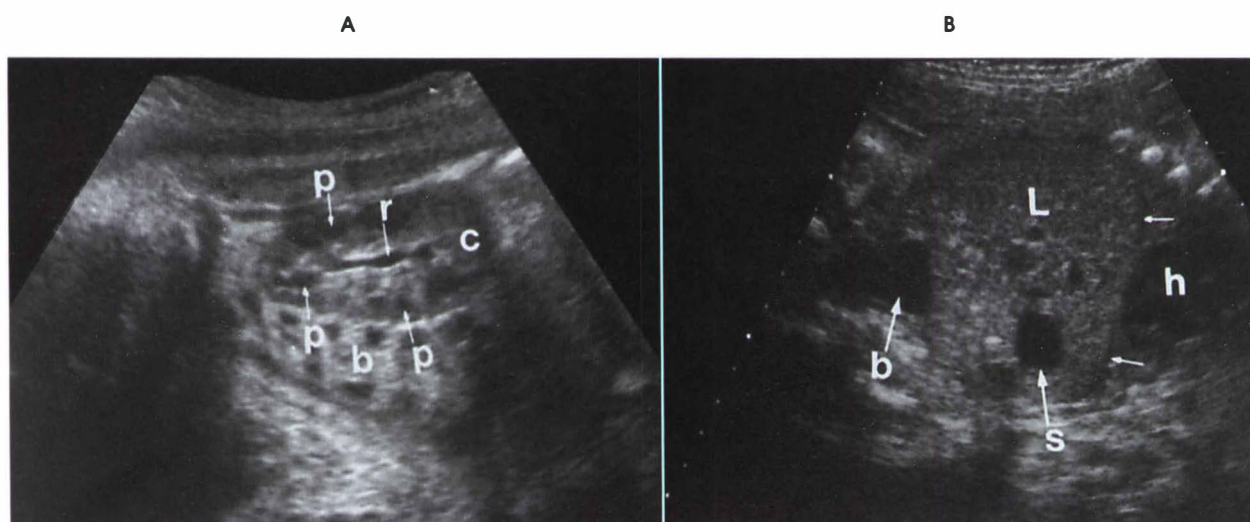
A patient who presents with a uterus larger than expected for the weeks of gestation may be scheduled for an ultrasound examination to assess fetal growth and fluid accumulation. The examination can also assess the patient for the presence of multiple gestations, the development of a hydatidiform mole, or the growth of a fibroid or extrauterine mass secondary to the pregnancy.

The fetal *biparietal diameter* (measurement taken perpendicular to the falx of the midline of the skull) may be measured after the twelfth week of gestation. Along with the fetal abdomen, femur, and head circumference, the biparietal diameter is useful in monitoring fetal growth by serial evaluations and measurements (Figs. 37-35 and 37-36).

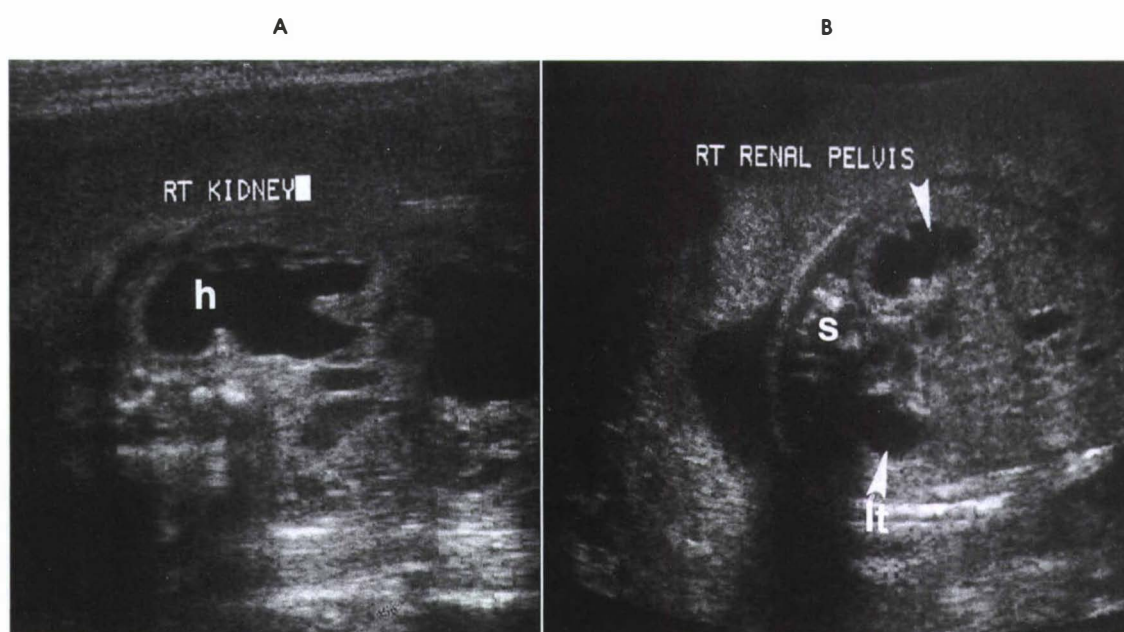


**Fig. 37-36 A**, Anatomic depiction at the ventricular level at 27 weeks of gestation. The open arrow points to a reverberation artifact in the proximal cranial hemisphere. The double-headed arrows point to fetal brain tissue. OC, Occiput; mL, interhemispheric fissure/falx; lvb, lateral ventricular border; c, choroid plexus; v, ventricular cavity; a, anterior chamber of the ventricle. Note the lateral ventricular border, which appears to lie less than halfway between the interhemispheric fissure and inner skull table (arrowhead). **B**, Anatomic depiction at the thalamic level in a 31-week fetus: T, thalamus; p, cerebral peduncles; v, third ventricle; s, cavum septum pellucidum; cc, area of corpus callosum; l, insula; c, choroid plexus; a, ambient cisterns; f, frontal lobe; ss, subarachnoid space; OC, occiput. **C**, Anatomic depiction at the skull base in a 31-week fetus. The double arrows indicate the cerebral peduncles. c, Cerebellum; CM, cisternal magna; i, insula; s, cavum septum pellucidum; OC, occiput.

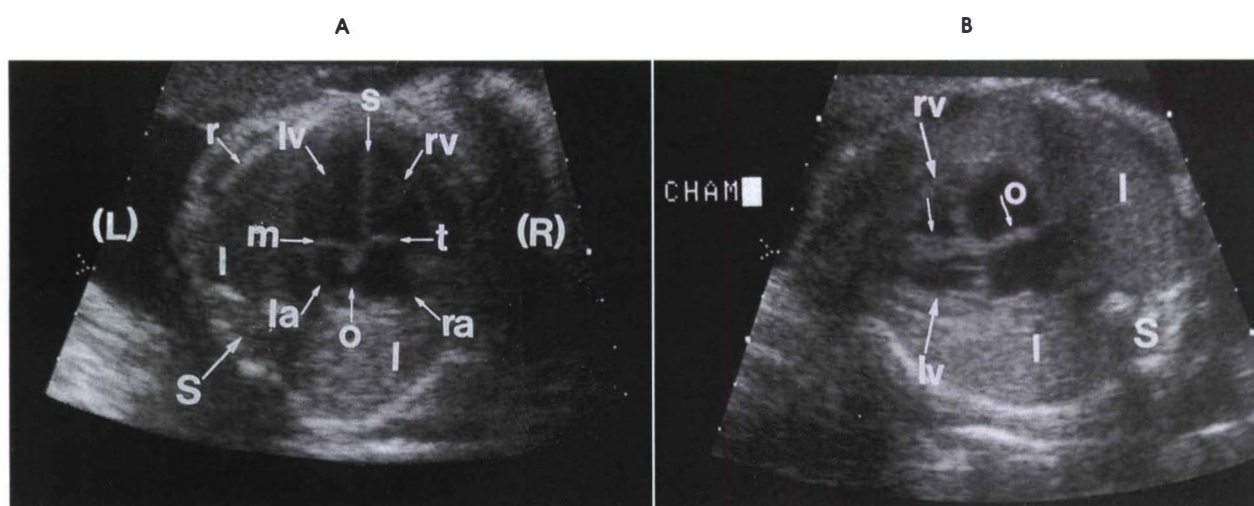
Ultrasound is helpful for defining both normal and abnormal development of anatomy. A detailed ultrasound examination can assess complications of pregnancy such as neural tube defects, skeletal or limb anomalies, cardiac defects, gastrointestinal and genitourinary defects, and head anomalies (Figs. 37-37 to 37-39).



**Fig. 37-37** **A**, Longitudinal image of the fetal kidney in a third trimester fetus showing the renal cortex (*c*), renal pelvis (*r*), and pyramids (*p*). The kidney is margined by the renal capsule, which is highly visible later in pregnancy because of perirenal fat (*b*, bowel). **B**, Sagittal image of the fluid-filled bladder (*b*) in the pelvis. The stomach (*s*) is shown in the upper abdomen with the liver (*L*); the heart (*h*) is above the diaphragm (*arrows*).



**Fig. 37-38** **A**, Sagittal and, **B**, transverse images of bilateral hydronephrosis (*h*) in the fetal kidneys. *S*, Spine.



**Fig. 37-39** **A**, Four chamber image in a 31 week fetus with the spine (*S*) at the 7 o'clock position. The left ventricle (*lv*) is separated from the right ventricle (*rv*) by the interventricular septum (*s*). The left atrium (*la*) is separated from the right atrium (*ra*) by the interatrial septum. The flap of the foramen ovale (*o*) opens into the left atrium during fetal life. The atria and ventricles are separated by atrioventricular valves. The mitral valve (*m*) is on the left and the tricuspid valve (*t*) is on the right. (*l*, Lungs.) **B**, In a 30 week fetus the heart is observed in the 5 o'clock position. The fetal left side is down.

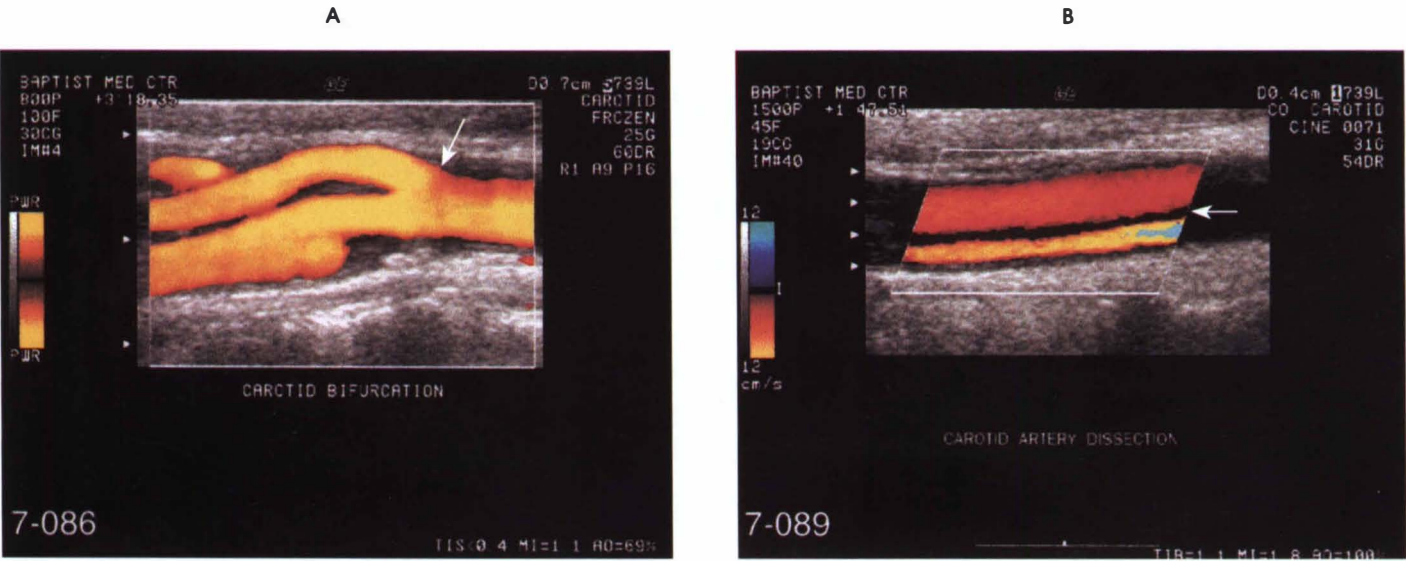


VASCULAR APPLICATIONS

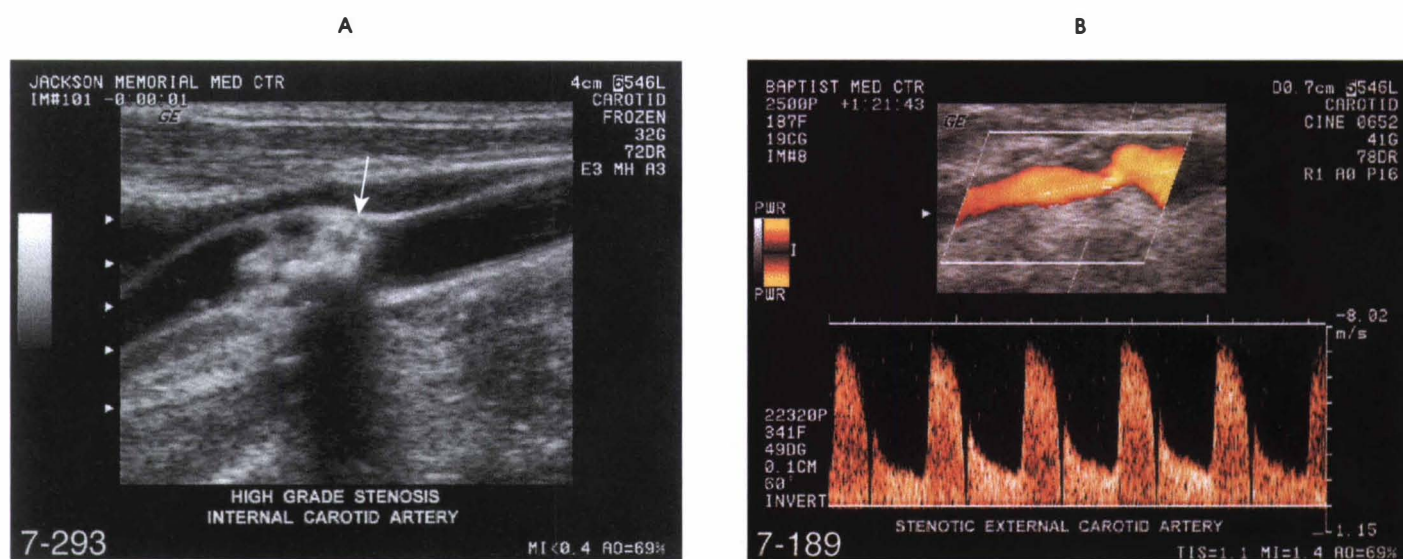
The use of ultrasound and color flow Doppler has enhanced the ability to image peripheral vascular structures in the body. The common carotid artery with its internal and external branches and the vertebral artery are well seen with high-frequency ultrasound (Fig. 37-40). The detection of plaque formation, thrombus, obstruction, or stenosis is documented with both color and spectral Doppler waveforms (Fig. 37-41).

The ultrasound facilitates good visualization of the common femoral artery and vein and their branches as they extend into the calf. Thrombus within a distended venous structure is identified when the sonographer is unable to compress the vein with the transducer. Color flow Doppler is also useful for denoting an absence of flow within a vessel. Arterial and venous structures may be reliably mapped using the ultrasound vascular mapping technique.

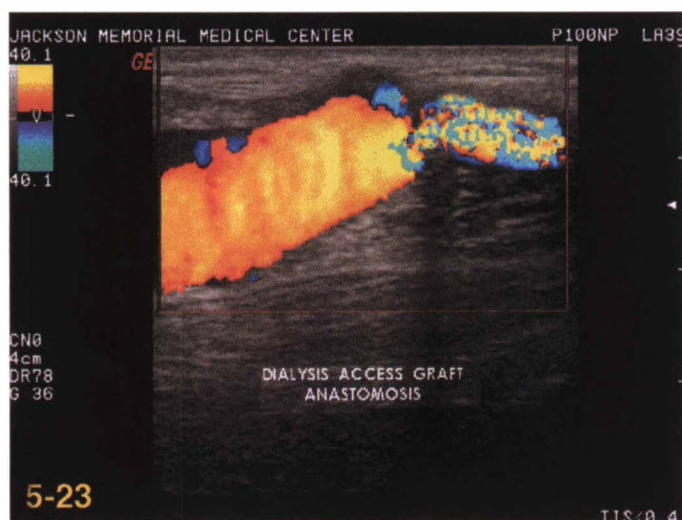
Ultrasound is also useful for imaging the patency of other vascular structures, such as the jugular vein, the subclavian artery and vein, the brachial artery and vein, and radial grafts (Fig. 37-42).



**Fig. 37-40 A,** Longitudinal image of the carotid artery and the bifurcation. **B,** Longitudinal image of the carotid artery that has dissected. Blood is shown between the intima and media layer of the vessel as yellow (arrow).



**Fig. 37-41** **A**, Longitudinal image of the carotid artery with a high grade stenosis at the bifurcation (*arrow*). **B**, Color Doppler and spectral waveform demonstrates increased flow velocity in the stenotic external carotid artery.



**Fig. 37-42** A dialysis patient with a access graft shows turbulence (*blue/green*) at the point of narrowing.

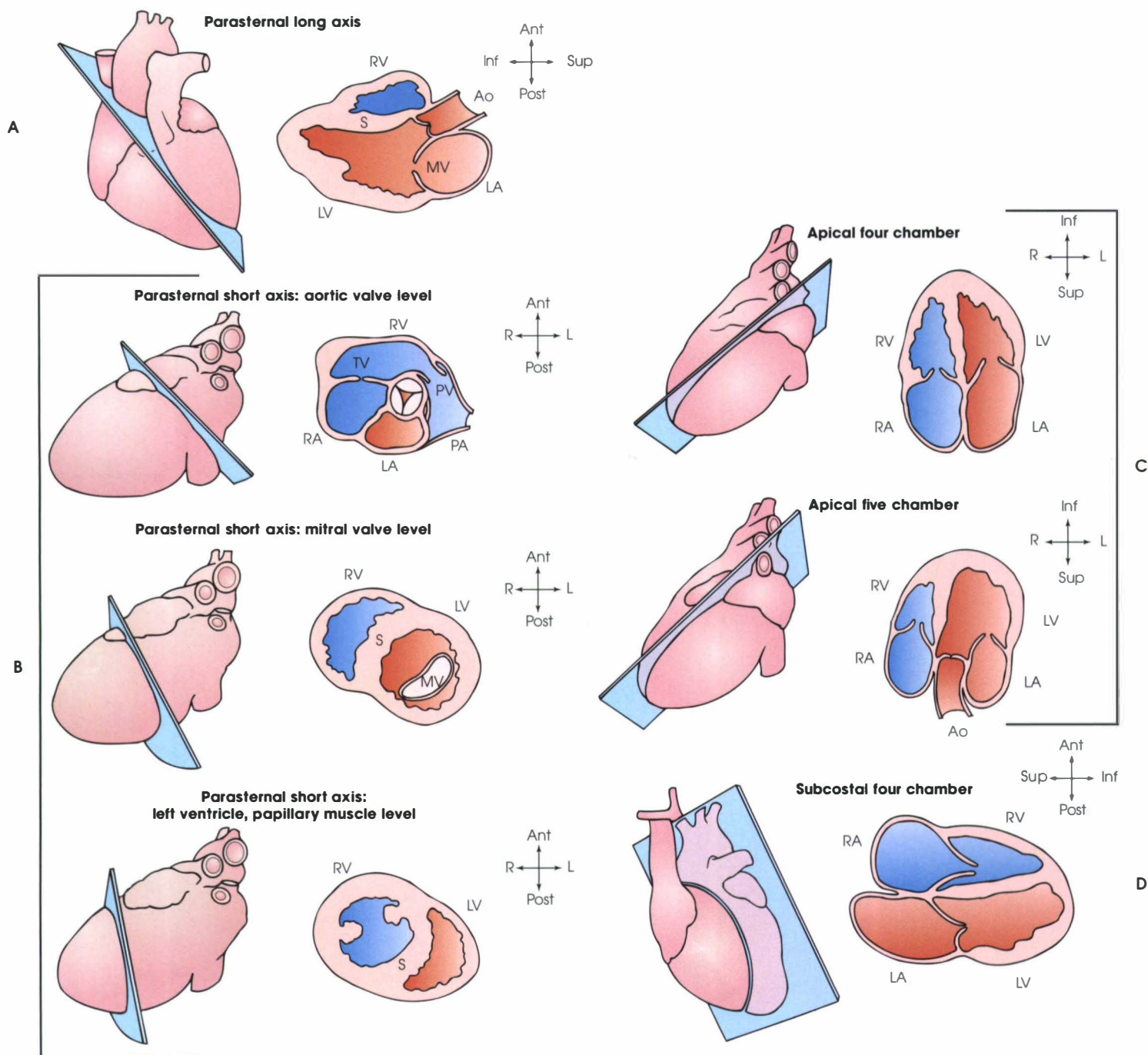
## Cardiologic Applications

Real-time echocardiography of the fetal, neonatal, pediatric, and adult heart has proven to be a tremendous diagnostic aid for the cardiologist and internist. A complete two-dimensional study of the heart uses real-time color flow Doppler with pulsed and continuous wave Doppler spectral tracings. With echocardiography, it is possible to image cardiac anatomy in detail, including the four chambers of the heart, the four heart valves (mitral, tricuspid, aortic, and pulmonic), the interventricular and interatrial septa, the muscular wall of the ventricles, the papillary muscles, and the chordae tendineae cordis. Difficult cases can be imaged using a transesophageal technique in which the transducer is passed from the mouth, through the esophagus, to the orifice of the stomach. This high-frequency transducer uses the “window” of the stomach and esophagus to exquisitely image intracardiac structures.

### PROCEDURE FOR ECHOCARDIOGRAPHY

The echocardiographic examination begins with the patient in a left lateral decubitus position. This position allows the heart to move away from the sternum and fall closer to the chest wall, thereby providing a better cardiac “window,” or open area for the sonographer to image. The transducer is placed in the third, fourth, or fifth intercostal space to the left of the sternum. The protocol for a complete echocardiographic examination includes images in the long axis, short axis, apical, and suprasternal windows (Fig. 37-43).





**Fig. 37-43** **A**, Parasternal long axis drawing: RV, right ventricle; Ao, aorta; LV, left ventricle; LA, left atrium, S, septum, MV, mitral valve. **B**, Parasternal short axis drawings at various levels. Aortic valve level: RA, right atrium; LA, left atrium; TV, tricuspid valve; RV, right ventricle; Ao, aorta; PV, pulmonic valve; PA, pulmonary artery. Mitral valve level: RV, right ventricle; S, septum; LV, left ventricle; MV, mitral valve. Left ventricle, papillary muscle level: RV, right ventricle; S, septum; LV, left ventricle. **C**, Apical four-chamber image: RV, right ventricle; LV, left ventricle; RA, right atrium; LA, left atrium. Apical five-chamber image: RA, right atrium; RV, right ventricle; LV, left ventricle; LA, left atrium; Ao, aorta. **D**, Subcostal four chamber image: RA, right atrium; RV, right ventricle; LA, left atrium; LV, left ventricle.

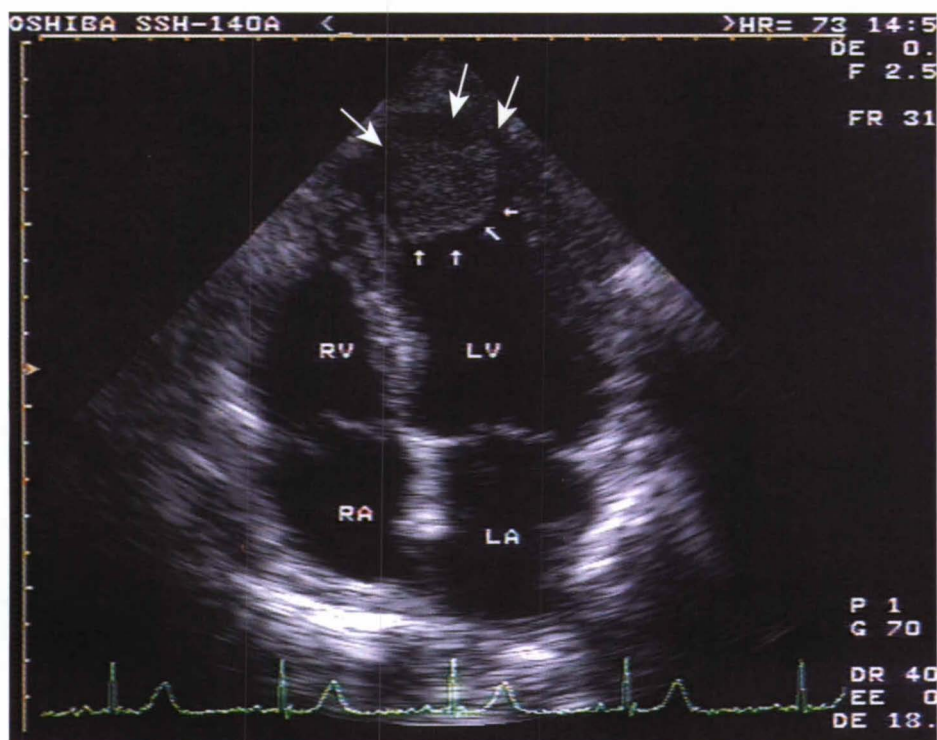
### CARDIAC PATHOLOGY

Echocardiography is used to evaluate many cardiac conditions. Atherosclerosis or previous rheumatic fever may lead to scarring, calcification, and thickening of the valve leaflets. With these conditions, valve tissue destruction continues, causing stenosis and regurgitation of the leaflets and subsequent chamber enlargement.

The effects of subbacterial endocarditis can also be evaluated with echocardiography. With this infectious process, multiple small vegetations form on the endocardial surface of the valve leaflets. This causes the leaflets to tear or thicken, with resultant severe regurgitation into subsequent cardiac chambers. The echocardiogram of a patient with congestive cardiomyopathy shows generalized four-chamber enlargement, valve regurgitation, and the threat of thrombus formation along the nonfunctioning ventricular wall. The pericardial sac surrounds the ventricles and right atrium and may fill with fluid, impairing normal cardiac function.

The analysis of ventricular function and the serial evaluation of patients after a myocardial infarction are accomplished with two-dimensional echocardiography and, in some cases, stress dobutamine echocardiography.

Complications of myocardial infarction (MI) may include rupture of the ventricular septum, development of a left ventricular aneurysm in the weakest area of the wall, or coagulation of thrombus in the akinetic or immobile apex of the left ventricle (Fig. 37-44).



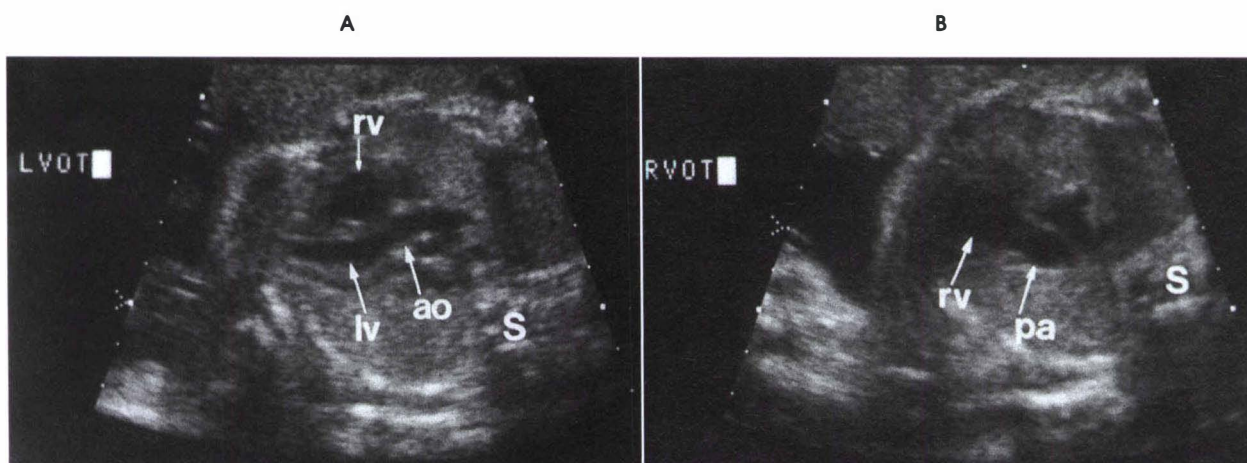
**Fig. 37-44** Apical four-chamber image with a large apical thrombus. This thrombus (arrows) is distinguished from an artifact because it is located in a region with abnormal wall motion, is attached to the apical endocardium, has well-defined borders, and moves in the same direction as the apex. RV, Right ventricle; LV, left ventricle; RA, right atrium; LA, left atrium.



### Congenital heart lesions

Echocardiography has been used to diagnose congenital lesions of the heart in fetuses, neonates, and young children. The cardiac sonographer is able to assess abnormalities of the four cardiac valves, determine the size of the cardiac chambers, assess the interatrial and interventricular septum for the presence of shunt flow, and identify the continuity of the aorta and pulmonary artery with the ventricular chambers to look for abnormal attachment relationships (Fig. 37-45).

The premature infant has an improved chance of survival if the correct diagnosis is made early. If the neonate is cyanotic, congenital heart disease or respiratory failure may be rapidly diagnosed with echocardiography. Critical cyanotic disease in the premature infant may include hypoplastic left heart syndrome, transposition of the great vessels with pulmonary atresia, or severe tetralogy of Fallot.



**Fig. 37-45** **A**, Long axis image of the fetal heart shows continuity of the anterior wall of the aorta (ao) with the interventricular septum. The right ventricle (rv) is anterior to the left ventricle (lv). The spine (S) is at the 4 o'clock position. **B**, Slight angulation to the right will show the pulmonary artery (pa) as it arises from the base of the right ventricle (rv). The spine is at the 3 o'clock position.

## Conclusion

The contribution of diagnostic ultrasound to clinical medicine has been facilitated by technologic advances in instrumentation and transducer design, increased ability to process the returned echo information, and improved methodology for the three-dimensional reconstruction of images. The development of high-frequency *endovaginal*, *endorectal*, and *transesophageal transducers* with endoscopic imaging has aided the visualization of previously difficult areas. Improved computer capabilities and advances in teleradiography have enabled the sonographer to obtain more information and process multiple data points to obtain a comprehensive report from the ultrasound study. Color flow Doppler has made it possible for the sonographer to distinguish the direction and velocity of arterial and venous blood flow from vascular and other pathologic structures in the body. Furthermore, Doppler has allowed the sonographer to determine the exact area of obstruction or leakage present and to determine precisely the degree of turbulence within a vessel or cardiac chamber.

Modifications in transducer design have improved resolution in superficial structures, muscles, and tendons. Advancements in equipment and transducer design have also improved the results of ultrasound examinations in neonates and children. Increased sensitivity allows the sonographer to define the texture of organs and glands with more detail and greater tissue differentiation. The improvements in resolution have aided the visualization of small cleft palate defects, abnormal development of fingers and toes, and small spinal defects. The ability to image the detail of the fetal heart has facilitated the early diagnosis of congenital heart disease.

Advanced research and development of the computer analysis and tissue characterization of echo reflections should further contribute to the total diagnostic approach using ultrasound. Various abdominal contrast agents continue to be investigated to improve visualization of the stomach, pancreas, and small and large intestine. Cardiac contrast agents are already being used to improve the visualization of viable myocardial tissue within the heart. Furthermore, saline and other contrast agents are being injected into the endometrial cavity to outline the lining of the endometrium for the purpose of distinguishing polyps and other lesions from the endometrial stripe.

Ultrasound has rapidly emerged as a powerful, noninvasive, high-yield clinical diagnostic examination for various applications in medicine. Expected advancements include further developments in transducer design, image resolution, tissue characterization applications, color flow sensitivity, and four-dimensional reconstruction of images.

## Definition of Terms

**acoustic impedance** Ratio of acoustic pressure to particle velocity at any point in the acoustic field.

**acoustic shadow** Loss of acoustic power of structures lying behind an attenuating or reflecting target.

**acoustic wave** Mechanical disturbance that propagates through a medium.

**a-mode (amplitude)** Method of acoustic echo display in which time is represented along the horizontal axis and echo amplitude is displayed along the vertical axis.

**anechoic** Property of being free of echoes or without echoes.

**angle of incidence** Angle at which the ultrasound beam strikes an interface with respect to normal (perpendicular) incidence.

**attenuation** Reduction of acoustic amplitude along propagation pathway as a result of diffraction, absorption, scattering, reflections, or any other process that redirects the signal away from the receiver.

**biparietal diameter (BPD)** Largest dimension of the fetal head perpendicular to the midsagittal plane; measured by ultrasonic visualization and used to measure fetal development.

**B-mode (brightness)** Method of acoustic display on an oscilloscope in which the intensity of the echo is represented by modulation of the brightness of the spot and in which the position of the echo is determined from the position of the transducer and the transit time of the acoustic pulse; displayed in the x-y plane.

**color flow Doppler** Velocity in each direction is quantified by allocating a pixel to each area; each velocity frequency change is allocated a color.

**continuous wave ultrasound** Waveform in which the amplitude modulation factor is less than or equal to a small value.

**coronal image plane** Anatomic term used to describe a plane perpendicular to both the sagittal and transverse planes of the body.

**cross-sectional display** Display that presents ultrasound interaction echo data from a single plane within a tissue. It is produced by sweeping the ultrasound beam through a given angle, by translating it along a line, or by some combination of linear and angular motions. The depth in the tissue is represented along one coordinate, and the position in the scan is represented by the second coordinate. The plane of the section may be sagittal, coronal, or transverse. The lateral resolution is determined by the beam width of the transducers.

**Doppler effect** Shift in frequency or wavelength, depending on the conditions of observation; caused by relative motions among the sources, receivers, and medium.

**Doppler ultrasound** Application of the Doppler effect to ultrasound to detect movement of a reflecting boundary relative to the source, resulting in a change of the wavelength of the reflected wave.

**dynamic imaging** Imaging of an object in motion at a frame rate sufficient to cause no significant blurring of any one image and at a repetition rate sufficient to adequately represent the movement pattern. This is frequently referred to as *imaging at a real-time (frame) rate*.

**echo** Reflection of acoustic energy received from scattering elements or a specular reflector.

**echogenic** Refers to a medium that contains echo-producing structures.

**endometrium** Refers to the inner layer of the uterine canal.

**endorectal transducer** High-frequency transducer that can be inserted into the rectum to visualize the bladder and prostate gland.

**endovaginal transducer** High-frequency transducer (and decreased penetration) that can be inserted into the vagina to obtain high-resolution images of the pelvic structures.

**focus** To concentrate the sound beam into a smaller beam area than would exist without focusing.

**frequency** Number of cycles per unit of time, usually expressed in Hertz (Hz) or megahertz (MHz; a million cycles per second).

**hard copy** Method of image recording in which data are stored on paper, film, or other recording material.

**heterogenous** Having a mixed composition.

**homogeneous** Having a uniform composition.

**hyperechoic** Producing more echoes than normal.

**hypoechoic** Producing fewer echoes than normal.

**ischemia** Refers to an area of the cardiac myocardium that has been damaged by disruption of the blood supply by the coronary arteries.

**isoechoic** Having a texture nearly the same as that of the surrounding parenchyma.

**intima** Refers to the inner layer of the vessel; the middle layer is the media and the outer layer is the adventitia.

**M-mode (motion)** Method in which tissue depth is displayed along one axis and time is displayed along the second axis.

**myometrium** The thick middle layer of the uterine wall

**noninvasive technique** A procedure that does not require the skin to be broken or an organ or cavity to be entered (e.g., taking the pulse).

**oblique plane** A slanting direction or any variation that is not starting at a right angle to any axis.

**parenchyma** The outer margin of the organ that is closest to the capsule.

**piezoelectric effect** Conversion of pressure to electrical voltage or conversion of electrical voltage to mechanical pressure.

**pulse wave ultrasound** Sound waves produced in pulse form by applying electrical pulses to the transducer.

**real-time imaging** Imaging with a real-time display whose output keeps pace with changes in input.



**reflection** Acoustic energy reflected from a structure with a discontinuity in the characteristic acoustic impedance along the propagation path.

**refraction** Phenomenon of bending wave fronts as the acoustic energy propagates from the medium of one acoustic velocity to a second medium of differing acoustic velocity.

**regurgitation** Occurs when blood leaks from one high pressure chamber to a chamber of lower pressure.

**resolution** Measure of the ability to display two closely spaced structures as discrete targets.

**retroperitoneal cavity** The area posterior to the peritoneal cavity that contains the aorta, inferior vena cava, pancreas, part of the duodenum and colon, kidneys and adrenal glands.

**scan** Technique for moving an acoustic beam to produce an image for which both the transducer and display movements are synchronized.

**scattering** Diffusion or redirection of sound in several directions on encountering a particle suspension or rough surface.

**sectional plane** Plane corresponding to transverse or sagittal plane.

**sonar** Instrument used to discover objects under the water and to show their location.

**sonic window** Sonographer's ability to visualize a particular area. For example, the full urinary bladder is a good sonic window to image the uterus and ovaries in a transabdominal scan. The intercostal margins may be a good sonic window to image the liver parenchyma.

**through transmission** Process of imaging by transmitting the sound field through the specimen and picking up the transmitted energy on a far surface or a receiving transducer.

**transducer** Device that converts energy from one form to another.

**ultrasound** Sound with a frequency greater than 20 kHz.

**velocity of sound** Speed with direction of motion specified.

**wave** Acoustic wave is a mechanical disturbance that propagates through a medium.

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38

# NUCLEAR MEDICINE

NANCY L. HOCKERT

Whole-body bone scan performed using  $^{99m}\text{Tc}$  with methylene diphosphonate (MDP) in a 50-year-old male patient with low back pain. The study was normal. Note the injection site in the right antecubital fossa.

## OUTLINE

Principles of nuclear medicine, 462  
History, 462  
Physical principles, 463  
Radiation safety in nuclear medicine, 468  
Instrumentation, 469  
Imaging methods, 472  
Clinical nuclear medicine, 478  
Bone mineral density, 484  
Conclusion, 485  
Definition of terms, 485





## Principles of Nuclear Medicine

Nuclear medicine is a medical specialty that focuses on the use of radioactive materials called *radiopharmaceuticals*\* for diagnosis, therapy, and medical research. Unlike radiologic procedures, which determine the presence of disease based on structural appearance, nuclear medicine studies determine the cause of a medical problem based on organ or tissue *function* (physiology).

In a nuclear medicine test the radioactive material, or *tracer*, is generally introduced into the body by injection, swallowing, or inhalation. Different tracers are used to study different parts of the body. Tracers are selected that localize in specific organs or tissues. The amount of radioactive tracer material is selected carefully to provide the lowest amount of radiation exposure to the patient and still ensure a satisfactory examination or therapeutic goal. Radioactive tracers produce *gamma-ray* emissions from within the organ being studied. A special piece of equipment, known as a *gamma* or *scintillation camera*, is used to transform these emissions into images that provide information about the function, primarily, and anatomy of the organ or system being studied. The camera records this information on a computer or on film.

Nuclear medicine tests are performed by a team of specially educated professionals: a nuclear medicine physician, a specialist with extensive education in the basic and clinical science of medicine who is licensed to use radioactive materials; a nuclear medicine technologist, who performs the tests and is educated in the theory and practice of nuclear medicine procedures; a physicist who is experienced in the technology of nuclear medicine and the care of the equipment, including computers; and a pharmacist or specially prepared technologist who is qualified to prepare the necessary radioactive pharmaceuticals.

## History

John Dalton is considered the father of the modern theory of *atoms* and molecules. In 1803, this English schoolteacher stated that all atoms of a given element are chemically identical, are unchanged by chemical reaction, and combine in a ratio of simple numbers. Dalton measured atomic weights in reference to hydrogen, to which he assigned the value of 1 (the atomic number of this element).

The discovery of x-rays by Wilhelm Conrad Roentgen in 1895 was a great contribution to physics and the care of the sick. A few months later another physicist, Henri Becquerel, discovered naturally occurring radioactive substances. In 1898 Marie Curie discovered two new elements in the uranium ore pitchblende. Curie named these trace elements *polonium* (after her homeland, Poland) and *radium*. Curie also coined the terms *radioactive* and *radioactivity*.

In 1923 Georg de Hevesy, often called the "father of nuclear medicine," developed the tracer principle. He coined the term *radioindicator* and extended his studies from inorganic to organic chemistry. The first radioindicators were naturally occurring substances such as radium and radon. The invention of the *cyclotron* by Ernest Lawrence in 1931 made it possible for de Hevesy to expand his studies to a broader spectrum of biologic processes by using phosphorus-32, sodium-22, and other cyclotron-produced (man-made) radioactive tracers.

Radioactive elements began to be produced in *nuclear reactors* developed by Enrico Fermi and his colleagues in 1946. The nuclear reactor greatly extended the ability of the cyclotron to produce radioactive tracers. A key development was the introduction of the *gamma camera* by Hal Anger in 1958. Another major event that contributed to the development of molecular nuclear medicine was the invention of the Univac digital computer, which was able to perform 5000 calculations per second. These advances, together with the invention of transistors, magnetic tape, and printed circuits, made feasible the continued growth of nuclear medicine.

The thyroid was one of the first organs to be examined by nuclear medicine studies using *external radiation detectors*. In the 1940s investigators found that the rate of incorporation of radioactive iodine by the thyroid gland was greatly increased in hyperthyroidism (overproduction of thyroid hormones) and greatly decreased in hypothyroidism (underproduction of thyroid hormones). Over the years tracers and instruments were developed to allow almost every major organ of the body to be studied by application of the tracer principle. Images subsequently were made of structures such as the liver, spleen, brain, and kidneys. Today the emphasis of nuclear medicine studies is more on function and chemistry than anatomic structure.

\*Almost all italicized words on the succeeding pages are defined at the end of this chapter.

## Physical Principles

An understanding of radioactivity must precede an attempt to grasp the principles of nuclear medicine and how images are created using radioactive compounds. The term *radiation* is taken from the Latin word *radii*, which refers to the spokes of a wheel leading out from a central point. The term *radioactivity* is used to describe the radiation of energy in the form of high-speed *alpha* or *beta particles* or waves (gamma rays), from the nucleus of an atom.

### BASIC NUCLEAR PHYSICS

The basic components of an atom include the nucleus, which is composed of varying numbers of *protons* and *neutrons*, and the orbiting *electrons*, which revolve around the nucleus in discrete energy levels. Protons have a positive electric charge, electrons have a negative charge, and neutrons are electrically neutral. Both protons and neutrons have masses nearly 2000 times the mass of the electron; therefore the nucleus composes most of the mass of an atom. This configuration can be described by the Bohr atomic model (Fig. 38-1). The total number of protons, neutrons, and electrons in an atom determines its characteristics, including its stability.

The term *nuclide* is used to describe an atomic species with a particular arrangement of protons and neutrons in the nucleus. Elements with the same number of protons but a different number of neutrons are referred to as *isotopes*. Isotopes have the same chemical properties as one another because the total number of protons and electrons is the same. They differ simply in the total number of neutrons contained in the nucleus. The neutron-to-proton ratio in the nucleus determines the stability of the atom. At certain ratios, atoms may be unstable, and a process known as spontaneous *decay* can occur as the atom attempts to regain stability. Energy is released in various ways during this decay, or return to *ground state*.

*Radionuclides* decay by the emission of alpha, beta, and gamma radiation. Most radionuclides reach ground state through various decay processes, including alpha, beta, or positron emission and *electron capture*, as well as several other methods. These decay methods determine the type of particles or gamma rays given off in the decay.

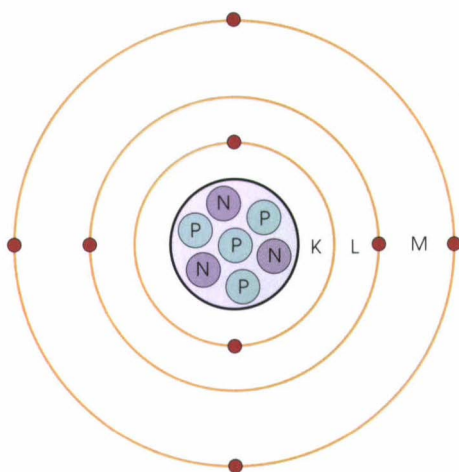


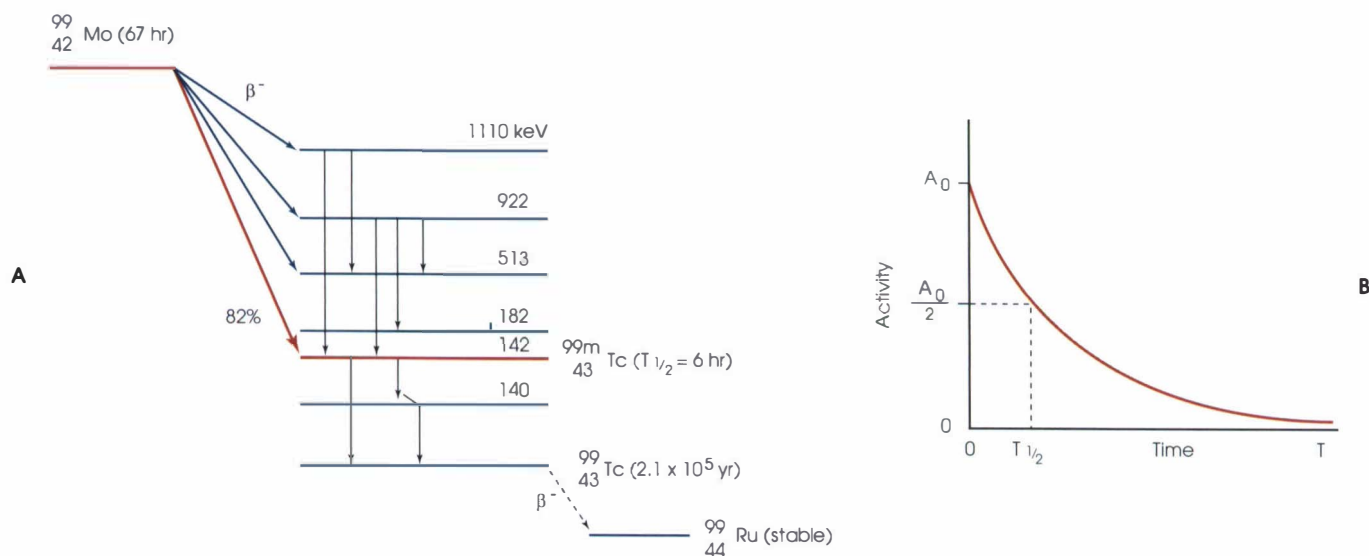
Fig. 38-1 Diagram of Bohr atom containing a single nucleus of protons (P) and neutrons (N) with surrounding orbital electrons of varying energy levels (K, L, M, etc.).

To better explain this process, investigators have created decay schemes to show the details of how a *parent* nuclide decays to its *daughter* or ground state (Fig. 38-2, A). Decay schemes are unique for each radionuclide and identify the type of decay, the energy associated with each process, the probability of a particular decay process, and the rate of change into the ground state element, commonly known as the *half-life* of the radionuclide.

Radioactive decay is considered a purely random and spontaneous process that can be mathematically defined by complex equations and represented by average decay rates. The term *half-life* ( $T_{1/2}$ ) is used to describe the time it takes for a quantity of a particular radionuclide to decay to one half of its original activity. This radioactive decay is a measure of the physical time it takes to reach one half of the original number of atoms through spontaneous disintegration. The rate of decay has an exponential function, which can be plotted on a linear scale (Fig. 38-2, B). If plotted on a semilogarithmic scale, the decay rate would be represented as a straight line. Radionuclide half-lives range from milliseconds to years. The half-lives of most radionuclides used in nuclear medicine range from several hours to several days.

## NUCLEAR PHARMACY

The radionuclides used in nuclear medicine are produced in reactors, or *particle accelerators*. Naturally occurring radionuclides have very long half-lives (i.e., thousands of years). These natural radionuclides are unsuitable for nuclear medicine imaging because of limited availability or the high absorbed dose the patient would receive. Thus the radionuclides for nuclear medicine are produced in a particle accelerator through nuclear reactions created between a specific target chemical and high-speed charged particles. The number of protons in the target nuclei is changed when the nuclei are bombarded by the high-speed charged particles, and a new element or radionuclide is produced. Radionuclides can be created in nuclear reactors either by inserting a target element into the reactor core where it is irradiated or by separating and collecting the *fission* products.



**Fig. 38-2 A**, Decay scheme illustrating the method by which radioactive molybdenum ( $^{99}\text{Mo}$ ) decays to radioactive technetium ( $^{99m}\text{Tc}$ ), one of the most commonly used radiopharmaceuticals in nuclear medicine. **B**, Graphic representation showing the rate of physical decay of a radionuclide. The y (vertical) axis represents the amount of radioactivity and the x (horizontal) axis represents the time at which a specific amount of activity has decreased to one half of its initial value. Every radionuclide has an associated half-life that is representative of its rate of decay.



The most commonly used radionuclide in nuclear medicine today is technetium- $^{99m}\text{Tc}$ , which is produced in a generator system. This system makes available desirable short-lived radionuclides—the *daughters*—which are formed by the decay of relatively longer-lived radionuclides—the *parents*. The generator system uses molybdenum-99 as the parent.  $^{99}\text{Mo}$  has a half-life of 66.7 hours and decays (86%) to a daughter product known as *metastable* technetium ( $^{99m}\text{Tc}$ ). Because technetium and molybdenum are chemically different, they can easily be separated through an ion-exchange column.  $^{99m}\text{Tc}$  exhibits nearly ideal characteristics for use in nuclear medicine examinations, including a relatively short physical half-life of 6.04 hours and a high-yield (98.6%) 140-keV, low energy, gamma photon (see Fig. 38-2, A).

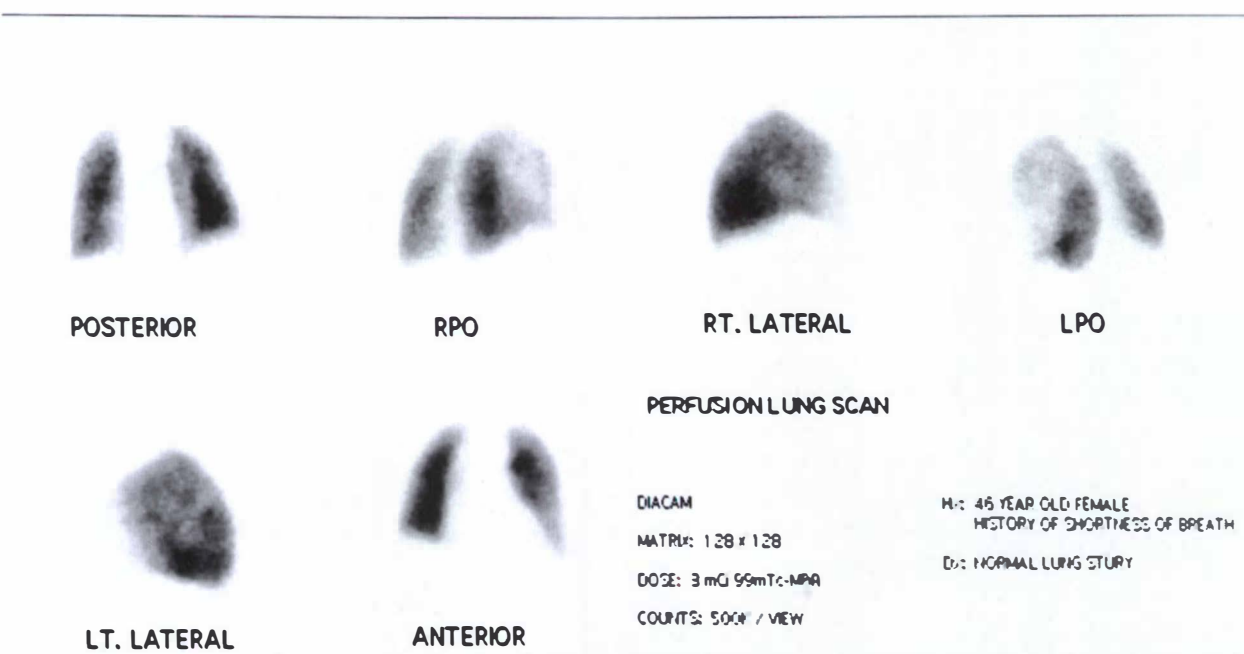
Because radiopharmaceuticals are administered to patients, they need to be sterile and *pyrogen free*. They also need to undergo all of the quality control measures required of conventional drugs. A radiopharmaceutical generally has two components: a *radionuclide* and a *pharmaceutical*. The pharmaceutical is chosen on the basis of its preferential localization or participation in the physiologic function of a given organ. A radionuclide is tagged to a pharmaceutical. After the radiopharmaceutical is administered, the target organ is localized and the radiation emitted from it can be detected by imaging instruments, gamma cameras.

The following characteristics are desirable in an imaging radiopharmaceutical:

- Ease of production and ready availability
- Low cost
- Lowest possible radiation dose
- Primary photon energy between 100 and 400 keV
- Physical half-life greater than the time required to prepare the material for injection
- Effective half-life longer than the examination time
- Suitable chemical forms for rapid localization
- Different uptake in the structure to be detected than in the surrounding tissue
- Low toxicity in the chemical form administered to the patient
- Stability or near-stability

$^{99m}\text{Tc}$  can be bound to biologically active compounds or drugs to create a radiopharmaceutical that localizes in a specific organ system or structure when the radionuclide is administered intravenously or orally. A commonly used radiopharmaceutical is  $^{99m}\text{Tc}$  tagged to a macroaggregated albumin (MAA). After IV injection, this substance follows the pathway of blood flow to the lungs, where it is distributed throughout and trapped in the small pulmonary capillaries (Fig. 38-3). Blood clots along the pathway prevent this radiopharmaceutical from distributing in the area beyond the clot. As a result the image shows a void or clear area, often described as *photopenia* or a *cold spot*. More than 30 different radiopharmaceuticals are used in nuclear medicine (Table 38-1).

Radiopharmaceutical doses vary, depending on the radionuclide used, the examination to be performed, and the size of the patient. The measure of radioactivity is expressed as either the *becquerel (Bq)*, which corresponds to the decay rate, expressed as one disintegration per second, or as the *curie (Ci)*, which equals  $3.73 \times 10^{10}$  disintegrations per second, relative to the number of decaying atoms in 1 g of radium.



**Fig. 38-3** Normal perfusion lung scan using 3 mCi of  $^{99m}\text{Tc}$  tagged to a macroaggregated albumin ( $^{99m}\text{Tc}$  MAA) on a large field-of-view gamma camera approximately 5 minutes after injection of the radiopharmaceutical. *RPO*, Right posterior oblique; *LPO*, left posterior oblique; *RT*, right; *LT*, left.

(Courtesy Siemens Medical Systems, Iselin, NJ.)

**TABLE 38-1**

Radiopharmaceuticals used in nuclear medicine

Radionuclide	Symbol	Physical half-life	Chemical form	Diagnostic use		
Chromium	<sup>51</sup> Cr	27.8 days	Sodium chromate Albumin	Red blood cell volume and survival Gastrointestinal protein loss		
Cobalt	<sup>57</sup> Co	270 days	Cyanocobalamin (vitamin B <sub>12</sub> )	Vitamin B <sub>12</sub> absorption		
	<sup>58</sup> Co	72 days	Cyanocobalamin (vitamin B <sub>12</sub> )	Vitamin B <sub>12</sub> absorption		
Gallium	<sup>67</sup> Ga	77 hours	Gallium citrate	Inflammatory process and tumor imaging		
Indium	<sup>111</sup> In	67.4 hours	Diethylenetriamine penta-acetic acid (DTPA)	Cerebrospinal fluid imaging		
			OncoScint(satumomab pendetide)	Colorectal or ovarian cancer		
			OctreoScan (pentetreotide)	Neuroendocrine tumors		
			ProstaScint (capromab pendetide)	Prostrate cancer		
			Oxine	White blood cell/abscess imaging		
			Sodium iodide	Thyroid function and imaging		
Iodine	<sup>123</sup> I	13.3 hours	Triiodothyronine	Thyroid hormone assay		
	<sup>125</sup> I	60 days	Thyroxine	Thyroid hormone assay		
			Other hormones or drugs	Radioassays		
			Human serum albumin	Plasma volume		
	<sup>131</sup> I	8 days	Sodium iodide	Thyroid function, imaging, and therapy		
			Hippurate	Renal function		
			Technetium	<sup>99m</sup> Tc	6 hours	Sodium pertechnetate
Sulfur colloid						Imaging of liver and spleen and renal transplants, lymphoscintigraphy
Macroaggregated albumin	Lung imaging					
Sestamibi	Cardiovascular imaging, myocardial perfusion					
DTPA	Brain and renal imaging					
Dimercaptosuccinic acid (DMSA)	Renal imaging					
Mertiatide (MAG <sub>3</sub> )	Renal imaging					
Diphosphonate	Bone imaging					
Pyrophosphate	Bone and myocardial imaging					
Red blood cells	Cardiac function imaging					
Hexamethylpropyleneamine- oxime (HMPAO)	Functional brain imaging					
Iminodiacetic (IDA) derivations	Liver function imaging					
Neurolite (Bicisate)	Brain imaging					
Myoview (Tetrofosmin)	Myocardial perfusion					
CEA-scan (Arcitumomab)	Gastrointestinal tract					
Cardiolite (Sestamibi)	Myocardial perfusion					
Depreotide (NeoTect)	Pulmonary lesions					
Apcitide (AcuTect)	Acute venous thrombosis					
Thallium	<sup>201</sup> Tl	73.5 hours	Thallous chloride	Myocardial imaging		
Xenon	<sup>133</sup> Xe	5.3 days	Xenon gas	Lung ventilation imaging		

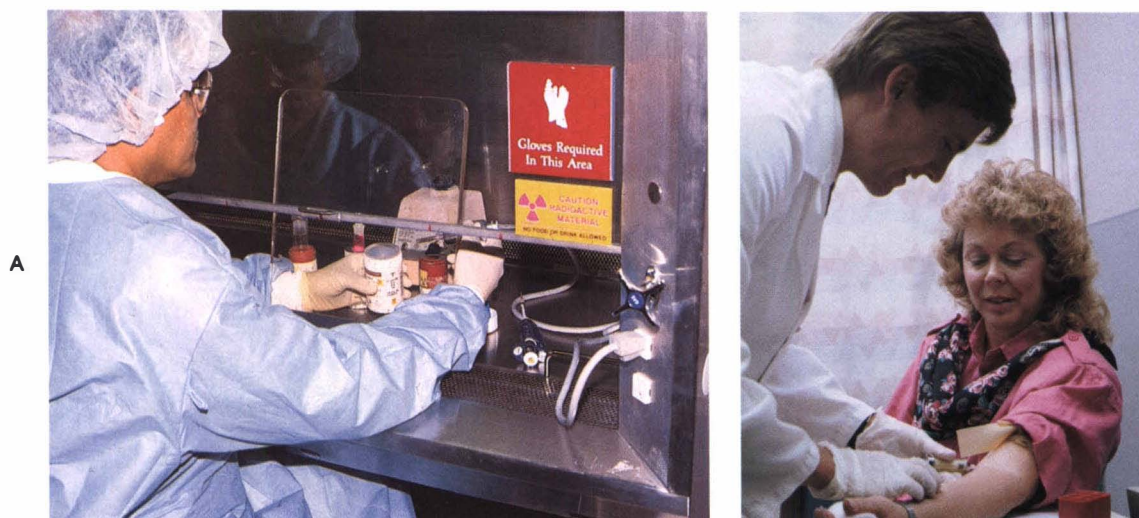


## Radiation Safety in Nuclear Medicine

The radiation protection requirements in nuclear medicine differ from the general radiation safety measures used for diagnostic radiography. The radionuclides employed in nuclear medicine are in liquid, solid, or gaseous form. Because of the nature of radioactive decay, these radionuclides continuously emit radiation after administration (unlike diagnostic x-rays, which can be turned on and off mechanically). Therefore special precautions are required.

In general, the quantities of radioactive tracers used in nuclear medicine present no significant hazard. Nonetheless, care must be taken to reduce unnecessary exposure. The high concentrations or activities of the radionuclides used in a nuclear pharmacy necessitate the establishment of a designated preparation area that contains isolated ventilation, protective lead or glass shielding for vials and syringes, absorbent material, and gloves. The handling and administering of diagnostic doses to patients warrants the use of gloves and a lead syringe shield, especially effective for reduction of exposure to hands and fingers during patient injection, at all times (Fig. 38-4). Any radioactive material that is spilled continues to emit radiation and therefore must immediately be cleaned up and contained. Because radioactive material that contacts the skin can be absorbed and may not be easily washed off, it is very important to wear protective gloves when handling radiopharmaceuticals.

Technologists and nuclear pharmacists are required to wear appropriate radiation monitoring (dosimetry) devices, such as film badges and thermoluminescent dosimetry (TLD) rings, to monitor radiation exposure to the body and hands. The ALARA (*as low as reasonably achievable*) program applies to all nuclear medicine personnel.



**Fig. 38-4** **A**, Area in a radiopharmacy in which doses of radiopharmaceuticals are prepared in a clean and protected environment. **B**, Nuclear medicine technologist administering a radiopharmaceutical intravenously using appropriate radiation safety precautions, including gloves and a syringe shield.

## Instrumentation

### RADIOACTIVE DETECTORS

#### Gas-filled detectors

For radioactivity to be detected, it must first interact with matter and release energy. When radioactivity strikes matter, as with gas molecules inside a detector, the gas ionizes (becomes charged), creating a voltage potential between two electrodes. This voltage potential is then used as a measure of the radioactivity present.

Two gas-filled radiation detectors are commonly used to detect and estimate the amount of radiation present. One is the Geiger-Mueller survey meter, usually called the *Geiger counter* (Fig. 38-5, A). The other is the dose calibrator, which is an ionization chamber used to measure the amount of radioactivity in a sample, such as a syringe, vial, or test tube (Fig. 38-5, B).

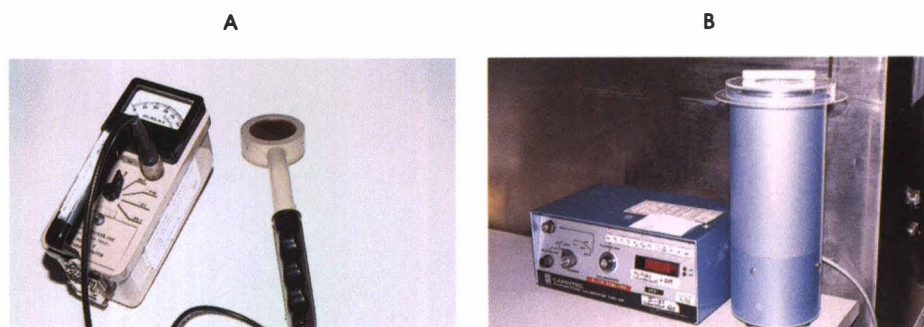
#### Scintillation detectors

The term *scintillate* means to emit light photons. Becquerel discovered that ionizing radiation caused certain materials to glow. A *scintillation detector* is a sensitive element used to detect ionizing radiation by observing the emission of light photons induced in a material. When a light-sensitive device is affixed to this material, the flash of light can be changed into small electrical impulses. The electrical impulses are then amplified so that they may be sorted and counted to determine the amount and nature of radiation striking the scintillating materials. Scintillation detectors were used in the development of the first-generation nuclear medicine scanner, the *rectilinear scanner*, which was built in 1950.

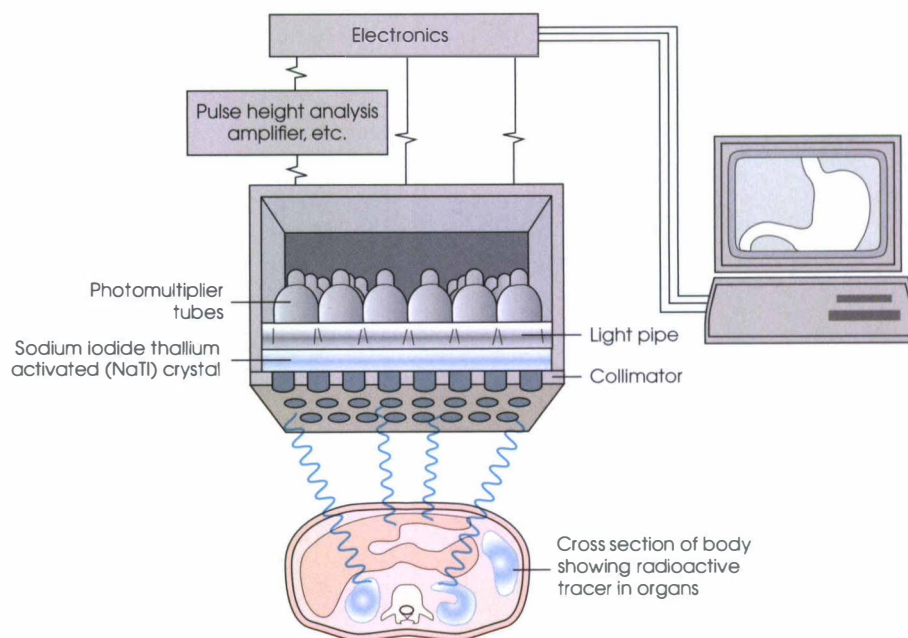
#### Modern-day gamma camera

Rectilinear scanners have evolved into complex imaging systems known today as *gamma cameras* (because they detect gamma rays). These cameras are still scintillation detectors that use a thallium-activated sodium iodide crystal to detect and transform radioactive emissions into light photons. Through a complex process, these light photons are amplified and their locations are electronically recorded to produce an image that is displayed as a hard copy or on computer output systems. Scintillation cameras with single or multiple crystals are used today. The gamma camera has many components that work together to produce an image (Fig. 38-6).

Gamma cameras can be either stationary or mobile. Mobile gamma cameras are used to perform bedside studies on patients who cannot be transported to the nuclear medicine department. The mobile cameras can be moved throughout the hospital, or they may be transported to other sites using a cross-country truck unit. Mobile gamma cameras typically have limitations, including a smaller field of view and less detector shielding; thus the types and quality of examinations that can be performed are restricted.



**Fig. 38-5** A, Geiger-Mueller survey meter used to detect and determine the relative amount of radioactivity present. B, Dose calibrator used to determine the amount of radioactivity in syringes or vials.



**Fig. 38-6** Typical gamma camera system, which includes complex computers and electronic mechanical components for acquiring, processing, displaying, and analyzing nuclear medicine images.



### Collimator

Located at the face of the detector, where photons from radioactive sources first enter the camera, is a *collimator*. The collimator is used to separate gamma rays and keep scattered rays from entering the scintillation crystal. *Resolution* and *sensitivity* are terms used to describe the physical characteristics of collimators. Collimator sensitivity is determined by the fraction of photons that are actually transmitted through the collimator and strike the face of the camera crystal. Spatial resolution is the capability of a system to produce an image in which the small details are observable.

Collimators are usually made of a material with a high atomic number, such as lead, which absorb scattered gamma rays. Different collimators are used for different types of examinations, depending on photon energy and the desired level of sensitivity and resolution.

### Crystal and light pipe

The scintillation crystals commonly used in gamma cameras are made of sodium iodide with trace quantities of thallium added to increase light production. This crystal composition is effective for stopping most common gamma rays emitted from the radiopharmaceuticals used in nuclear medicine.

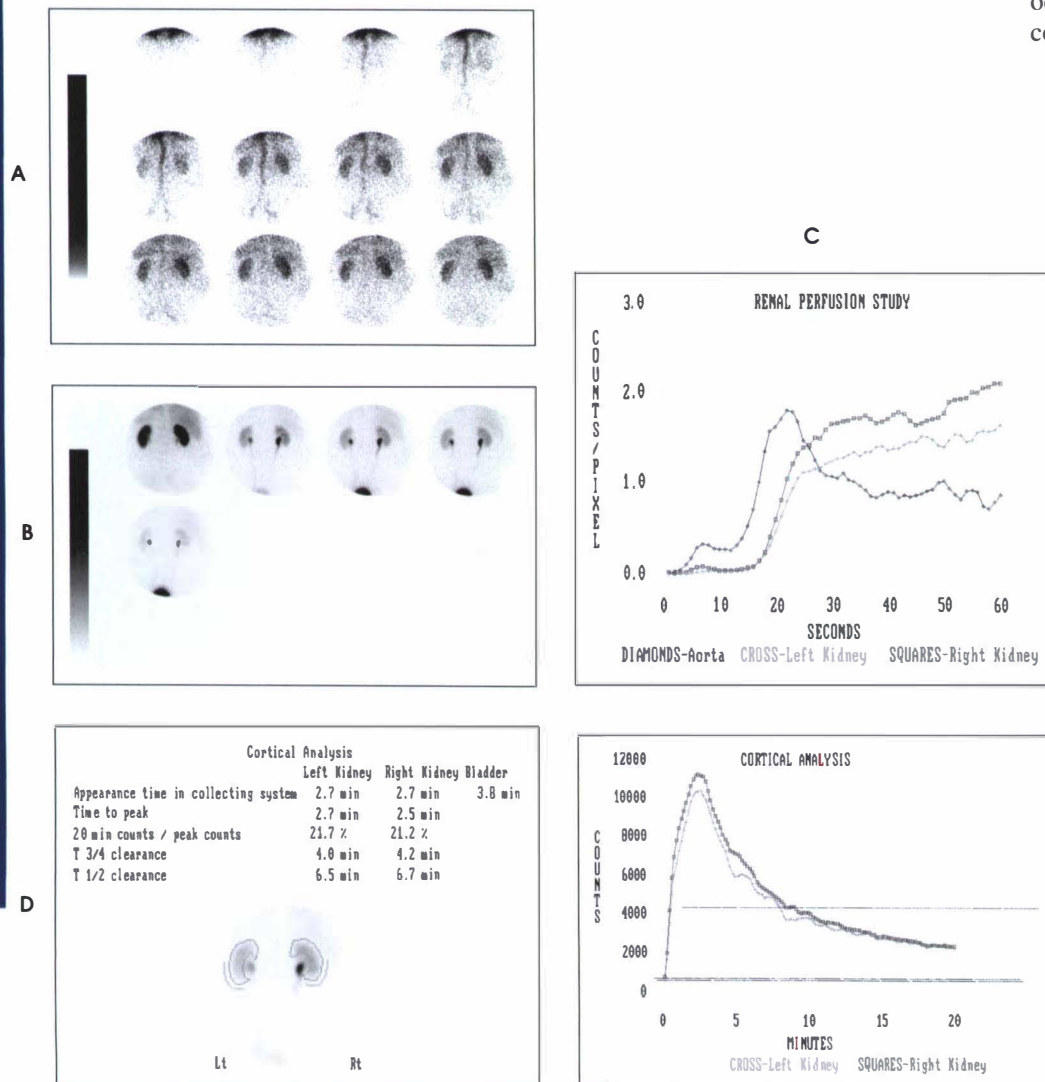
The thickness of the crystal varies from  $\frac{1}{4}$  inch to  $\frac{1}{2}$  inch (0.6 to 1.3 cm). Thicker crystals are better for imaging radiopharmaceuticals with higher energies (more than 180 keV) but have decreased resolution. Thinner crystals provide improved resolution but cannot efficiently image photons with a higher kiloelectron voltage.

A *light pipe* may be used to attach the crystal to the *photomultiplier tubes* (PMTs). The light pipe is a disk of optically transparent material that helps direct photons from the crystal into the PMTs.

### Detector electronics

An array of PMTs are attached to the back of the crystal or light pipe. Inside the detector are PMTs used to detect and convert light photons emitted from the crystal into an electronic signal that amplifies the original photon signal by a factor of as much as  $10^7$ . A typical gamma camera detector head contains 80 to 100 PMTs.

The PMTs send the detected signal through a series of processing steps, which include determining the location (x, y) of the original photon and its amplitude or energy (z). The x and y values are determined by where the photon strikes the crystal. Electronic circuitry known as a *pulse height analyzer* is used to eliminate the z signals that are not within a desired preset energy range for a particular radionuclide. This helps reduce scattered lower energy, unwanted photons ("noise") that generally would degrade resolution of the image. Once the information has been processed, the signals are transmitted to the display system, which includes a cathode ray tube and a film imaging system or computer to record the image.



**Fig. 38-7** **A**, Posterior renal blood flow in an adult patient using 10 mCi of  $^{99m}\text{Tc}$  with diethylenetriamine pentaacetic acid (DTPA) imaged at 3 seconds per frame. The image in the lower right corner is a blood-pool image taken immediately after the initial flow sequence. Together the images demonstrate normal renal blood flow to both kidneys. **B**, Normal, sequential dynamic 20-minute  $^{99m}\text{Tc}$  with mercuric diethylenetriamine pentaacetate (MAG<sub>3</sub>) images. **C**, Renal arterial perfusion curves showing minor renal blood flow asymmetry. **D**, Renal cortical analysis curves showing rapid uptake and prompt parenchymal clearance. **E**, Quantitative renal cortical analysis indices showing normal values.



### Multihead gamma camera systems

The standard gamma camera is a single detector that can be moved in various positions around the patient. Gamma camera systems may include as many as three detectors (heads). Dual-head gamma camera systems allow simultaneous anterior and posterior imaging and may be used for whole-body bone or tumor imaging. Triple-head systems may be used for brain and heart studies. Although these systems are primarily suited for single photon emission computed tomography (SPECT), they can also provide multiplanar images. Find more detailed information under *Imaging Methods* later in this chapter.

### COMPUTERS

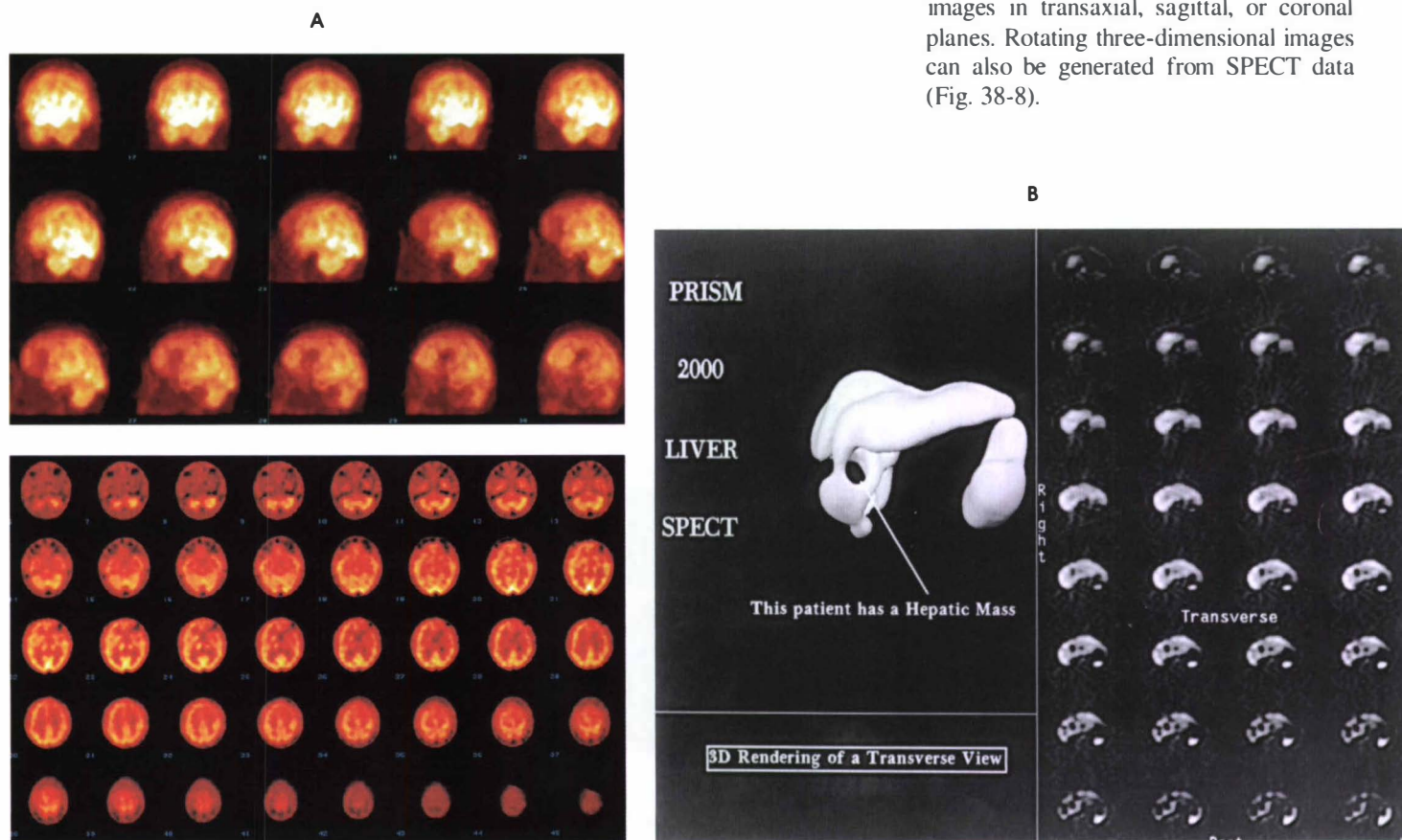
Computers have become an integral part of the nuclear medicine imaging system. Computer systems are used to acquire and process data from gamma cameras. They allow data to be collected over a specific time frame or to a specified number of counts; the data can then be analyzed to determine functional changes occurring over time (Fig. 38-7, A and B). A common example is the renal study, in which the radiopharmaceutical that is administered is cleared by normally functioning kidneys in about 20 minutes. The computer can collect images of the kidney during this period and analyze the images to determine how effectively the kidneys clear the radiopharmaceutical (Fig. 38-7, C, D, and E). The computer also allows the operator to enhance a particular structure by adjusting the contrast and brightness of the image.

Electronically stored records can decrease reporting turnaround time, physical image storage requirements, and the use of personnel for record maintenance and retrieval. Long-term computerized records

can also form the basis for statistical analysis to improve testing methods and predict disease courses.

Computerization of the nuclear pharmacy operation also has become an important means of record keeping and quality control. Radioactive dosages and dose volumes can be calculated more quickly by computer than by hand. The nuclear pharmacy computer system may be used to provide reminders and keep records as required by the Nuclear Regulatory Commission (NRC), the U.S. Food and Drug Administration (FDA), and individual state regulatory agencies. Computers can also assist in the scheduling of patients, based on dose availability and department policies.

Computers are necessary to acquire and process SPECT images, to be discussed in the next section. SPECT uses a scintillation camera that moves around the patient to obtain images from multiple angles for tomographic image reconstruction. SPECT studies are complex and, like magnetic resonance imaging (MRI) studies, require a great deal of computer processing to create images in transaxial, sagittal, or coronal planes. Rotating three-dimensional images can also be generated from SPECT data (Fig. 38-8).



**Fig. 38-8** **A**, Three-dimensional single photon emission computed tomography (SPECT) brain study using 20 mCi of  $^{99m}\text{Tc}$  ethylcysteinate dimer (ECD) showing a patient with a left frontal lobe brain infarct (*top*) and baseline and Diamox challenge transaxial, coronal, and sagittal images of the same patient, showing the left frontal lobe brain infarct (*bottom*). **B**, Three-dimensional SPECT liver study using 8 mCi of  $^{99m}\text{Tc}$  sulfur colloid. A mass is seen on both the three-dimensional image (*top*) and the transaxial images (*bottom*).

Computer networks are becoming an integral part of the way a department communicates information within and among institutions. In a network, several or many computers are connected so that they all have access to the same files, programs, printers, etc. Networking allows the movement of both image-based and text-based data to any computer or printer in the network. Networking improves the efficiency of a nuclear medicine department. A computer network can serve as a vital component, reducing the time expended on menial tasks while allowing retrieval and transfer of information. Consolidation of all reporting functions in one area eliminates the need for the nuclear medicine physician to travel between departments to read studies. Centralized archiving, printing, and retrieval of the majority of image-based and nonimage-based data have increased the efficiency of data analysis, reduced the cost of image hard copy, and permitted more sophisticated analysis of image data than would routinely be possible.

## QUANTITATIVE ANALYSIS

Many nuclear medicine procedures require some form of quantitative analysis to provide physicians with numeric results based on and depicting organ function. Specialized software allows computers to collect, process, and analyze functional information obtained from nuclear medicine imaging systems. Cardiac ejection fraction is one of the more common quantitation studies (Fig. 38-9). In this dynamic study of the heart's contractions and expansions, the computer accurately determines the ejection fraction, or the amount of blood pumped out of the left ventricle with each contraction.

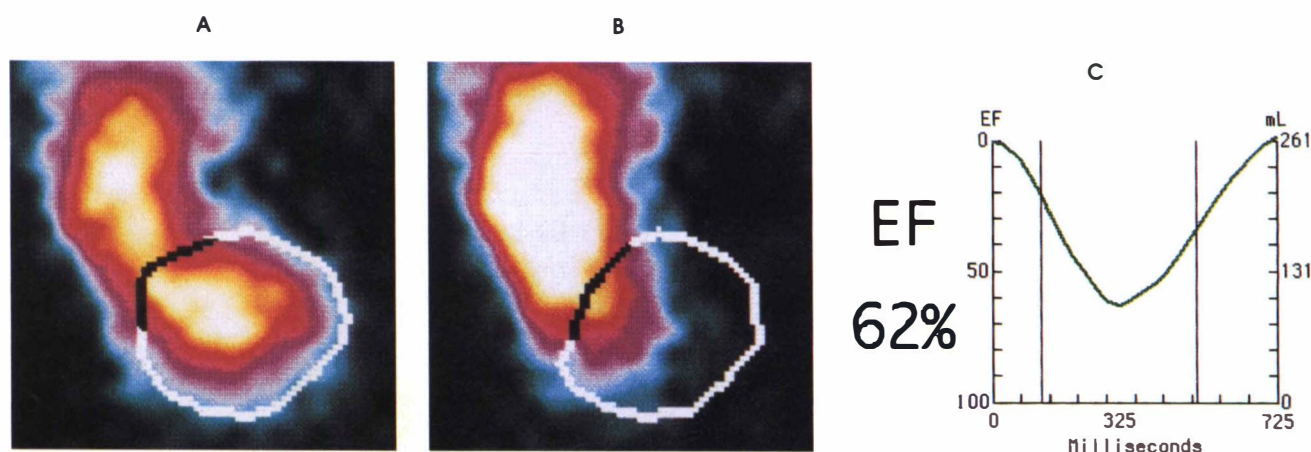
## Imaging Methods

A wide variety of diagnostic imaging examinations are performed in nuclear medicine. These examinations can be described on the basis of the imaging method used: static, whole body, dynamic, SPECT, and positron emission tomography (PET) (see Chapter 40).

## STATIC IMAGING

Static imaging is the acquisition of a single image of a particular structure. This image can be thought of as a "snapshot" of the radiopharmaceutical distribution within a part of the body. Examples of static images include lung scans, spot bone scan images, and thyroid images. Static images are usually obtained in various orientations around a particular structure to demonstrate all aspects of that structure. Anterior, posterior, and oblique images are often obtained.

In static imaging, low radiopharmaceutical activity levels are used to minimize radiation exposure to the patients. Because of these low activity levels, images must be acquired for a preset time or a minimum number of counts or radioactive emissions. This time frame may vary from a few seconds to several minutes to acquire 100,000 to more than 1 million counts. Generally, it takes from 30 seconds to 5 minutes to obtain a sufficient number of counts to produce a satisfactory image.



**Fig. 38-9** Gated first pass cardiac study and quantitative results, including the cardiac ejection fraction, of a normal patient. **A**, This is an anterior image of the left ventricle at end-diastole (relaxed phase), with a region of interest drawn around the left ventricle. **B**, Same view showing end-systole (contracted phase). **C**, Curve representing the volume change in the left ventricle of the heart before, during, and after contraction. This volume change is referred to as the ejection fraction (EF), with a normal value being approximately 62%.



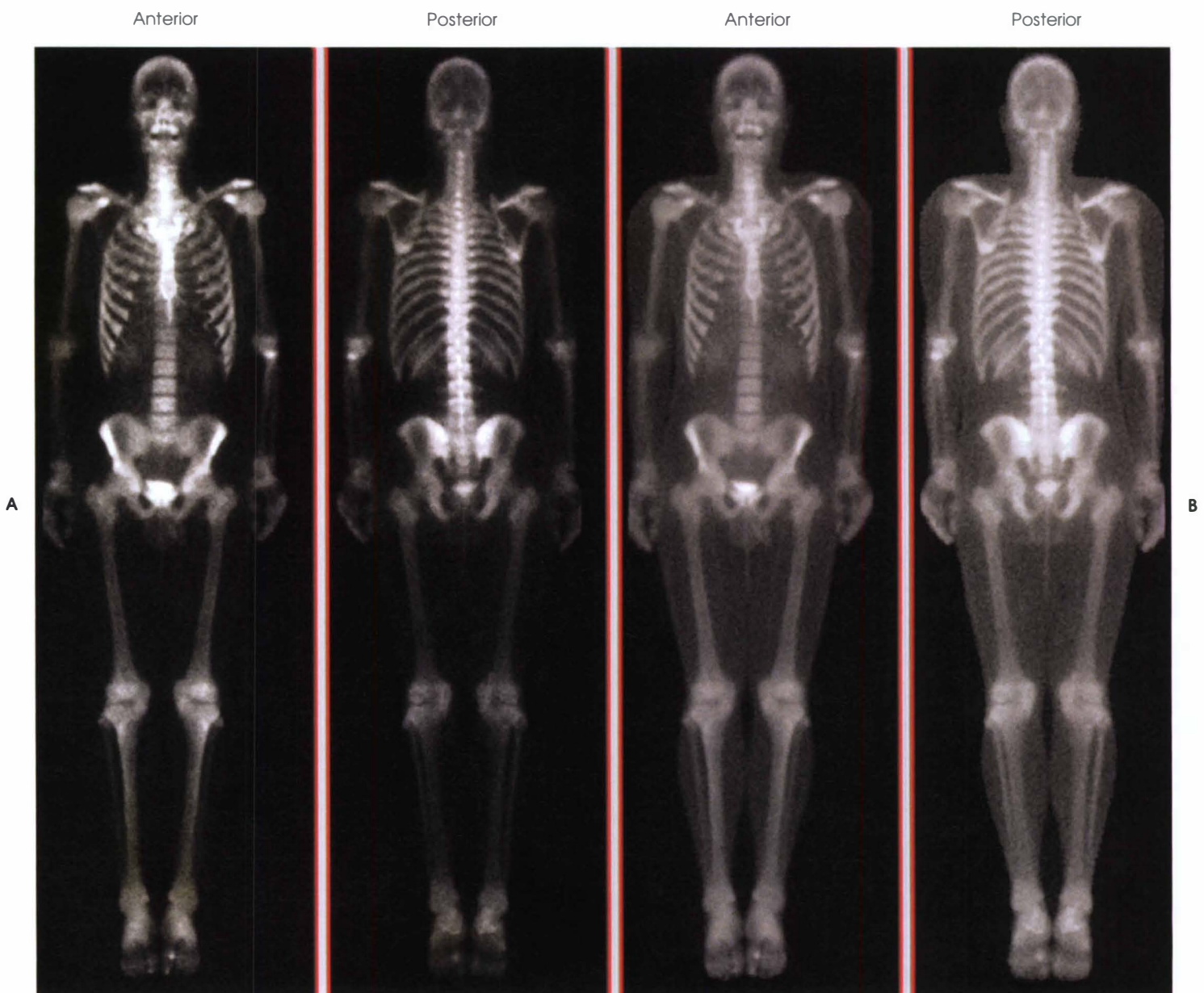
### WHOLE-BODY IMAGING

Whole-body imaging uses a specially designed moving detector system to produce an image of the entire body or a large body section. In this type of imaging, the gamma camera collects data as it passes over the body. Earlier detector systems were smaller and required as many as two or three incremental passes to encompass the entire width of the body.

During the past several years the detector width for whole-body systems has been increased to allow for a single head-to-foot pass that encompasses the entire body from side to side. These systems may also include dual heads for simultaneous anterior and posterior imaging. Whole-body imaging systems are used primarily for whole-body bone scans, whole-body tumor or abscess imaging, and other clinical and research applications (Fig. 38-10).

### DYNAMIC IMAGING

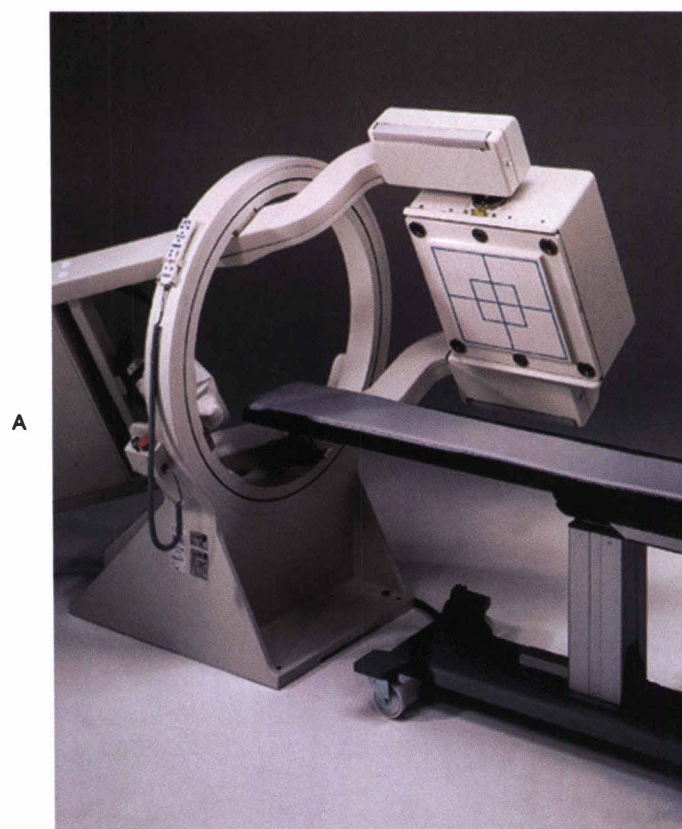
Dynamic images display the distribution of a particular radiopharmaceutical over a specific period. A dynamic or "flow" study of a particular structure is generally used to evaluate blood perfusion to the tissue. This can be thought of as a sequential or time-lapse image. Images may be acquired and displayed in time sequences as short as one tenth of a second to longer than 10 minutes per image. Dynamic imaging is commonly used for first-pass cardiac studies, hepatobiliary studies, and gastric emptying studies.



**Fig. 38-10** Whole-body scan performed using 25 mCi  $^{99m}\text{Tc}$  hydroxymethylene diphosphate (HDP) in a 25-year-old male. The study was normal. **A**, Anterior and posterior whole-body view in a linear gray scale. **B**, Anterior and posterior whole-body view in a Square Root gray scale, to enhance soft tissue.

(Courtesy of General Electric.)

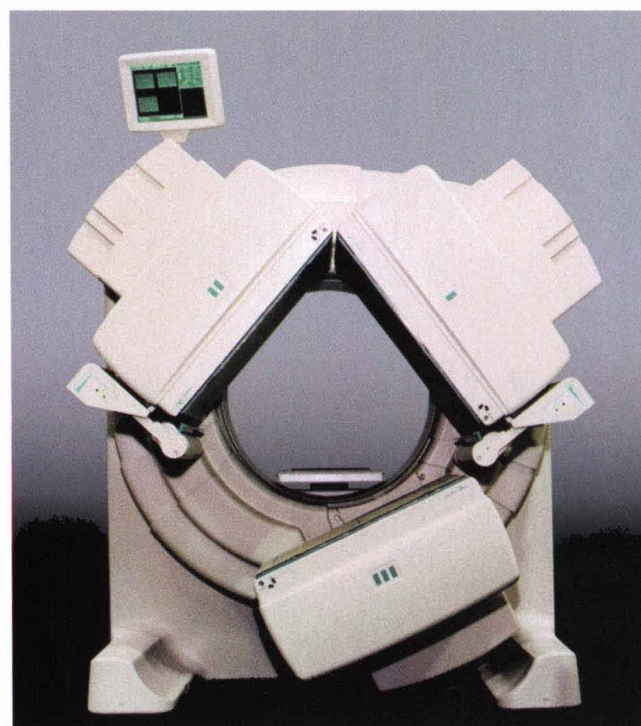




A



B



C

**Fig. 38-11** Single photon emission computed tomography (SPECT) camera systems. **A**, Single-head system. **B**, Dual-headed system. **C**, Triple-headed system.

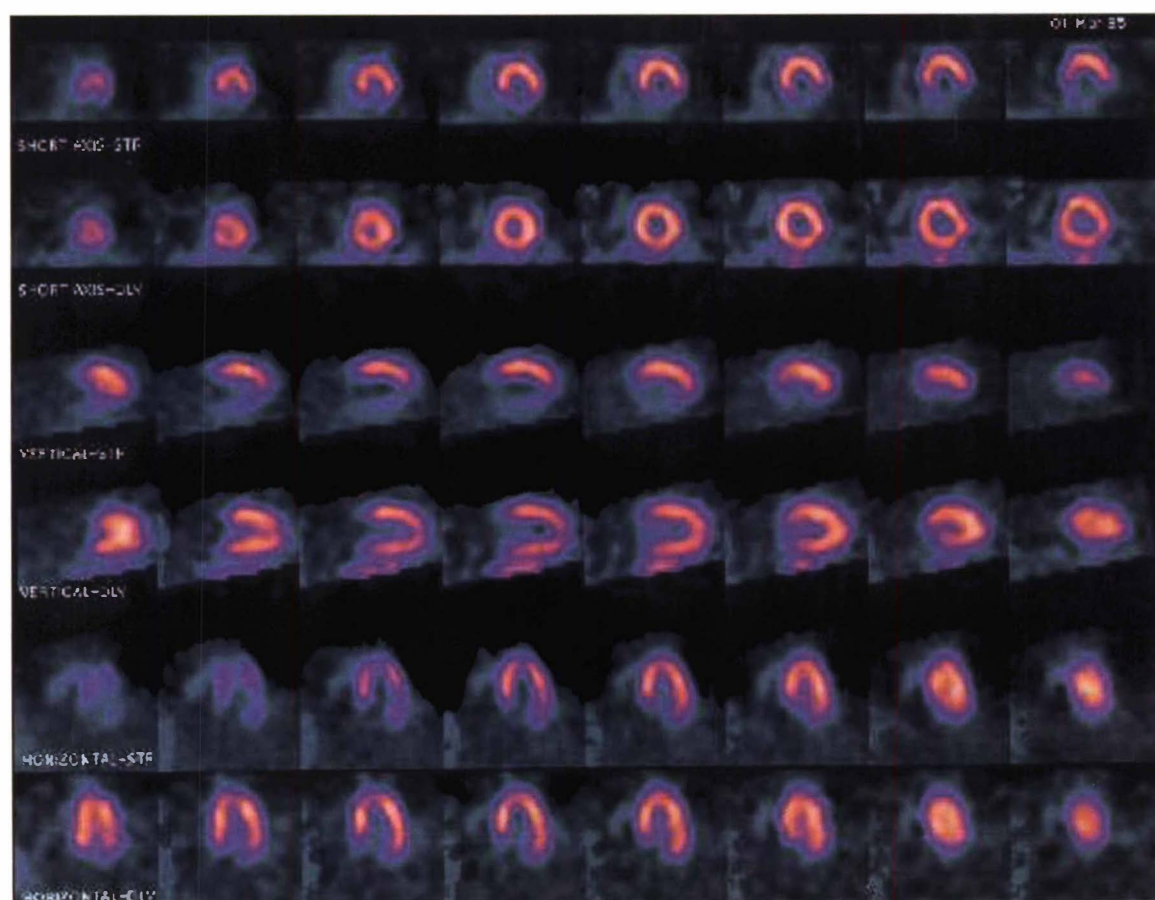
(**A**, Courtesy of General Electric; **B**, Courtesy of Siemens Medical Systems, Inc.; **C**, Courtesy of Marconi Medical Systems.)

## SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY

SPECT produces images similar to those obtained by CT or MRI in that a computer creates thin slices through a particular organ. This imaging technique has proved very beneficial for delineating small lesions within tissues, and it can be used on virtually any structure or organ. Improved clinical results with SPECT are due to improved target-to-nontarget ratios. Planar images record and demonstrate all radioactivity emitting from the patient above and below the region of interest, causing degradation of the image. In contrast, SPECT eliminates the unnecessary information.

With SPECT, one to three gamma detectors may be used to produce tomographic images (Fig. 38-11). Tomographic systems are designed to allow the detector heads to rotate as much as 360 degrees around a patient's body to collect "projection" image data. The image data are reconstructed by a computer in several formats, including transaxial, sagittal, coronal, planar, and three-dimensional representations. The computer-generated images allow for the display of thin slices through different planes of an organ or structure, thereby helping to identify small abnormalities.

The most common uses of SPECT include cardiac perfusion, brain, liver (see Fig. 38-8, *B*), and bone studies. An example of a SPECT study is the myocardial perfusion thallium study, which is used to identify perfusion defects in the left ventricular wall. Radioactive thallium is injected intravenously while the patient is being physically stressed on a treadmill or is being infused with a vasodilator. The radiopharmaceutical distributes in the heart muscle in the same fashion as blood flowing to the tissue. An initial set of images is acquired immediately after the stress test. A second set is obtained several hours later when the patient is rested (when the thallium has redistributed to viable tissue) to determine whether any blood perfusion defects that were seen on the initial images have resolved. By comparing the two image sets, the physician may be able to tell whether the patient has damaged heart tissue resulting from a myocardial infarction or myocardial ischemia (Fig. 38-12).



**Fig. 38-12** Thallium-201 myocardial perfusion study comparing stress and redistribution (resting) images in various planes of the heart (short axis and long axis). A perfusion defect is identified in the stress images but not seen in the redistribution (rest) images. This finding is indicative of ischemia.



### POSITRON EMISSION TOMOGRAPHY

PET imaging uses positron emissions from particular radionuclides to produce detailed functional images within the body. PET is unique in that its images are of blood flow or metabolic processes at the cellular level rather than the more conventional anatomic images produced by x-ray, CT, MRI, or even SPECT. A positron emitter releases two identical photons that travel in exactly opposite directions. These photons are of high energy (511 keV) and require special imaging by two opposing (180°) detectors. Because the positron radiopharmaceuticals generally have short half-lives of anywhere from a few seconds to a few hours, they must be produced in a cyclotron located near the imaging facility or through a specially designed generator system. One of the more common PET procedures uses fluorine-18 fluorodeoxyglucose to measure glucose metabolism in the brain (Fig. 38-13). PET is also frequently used to detect tumors in the body, which generally have a very high rate of glucose uptake. (For additional discussion, see Chapter 40.)

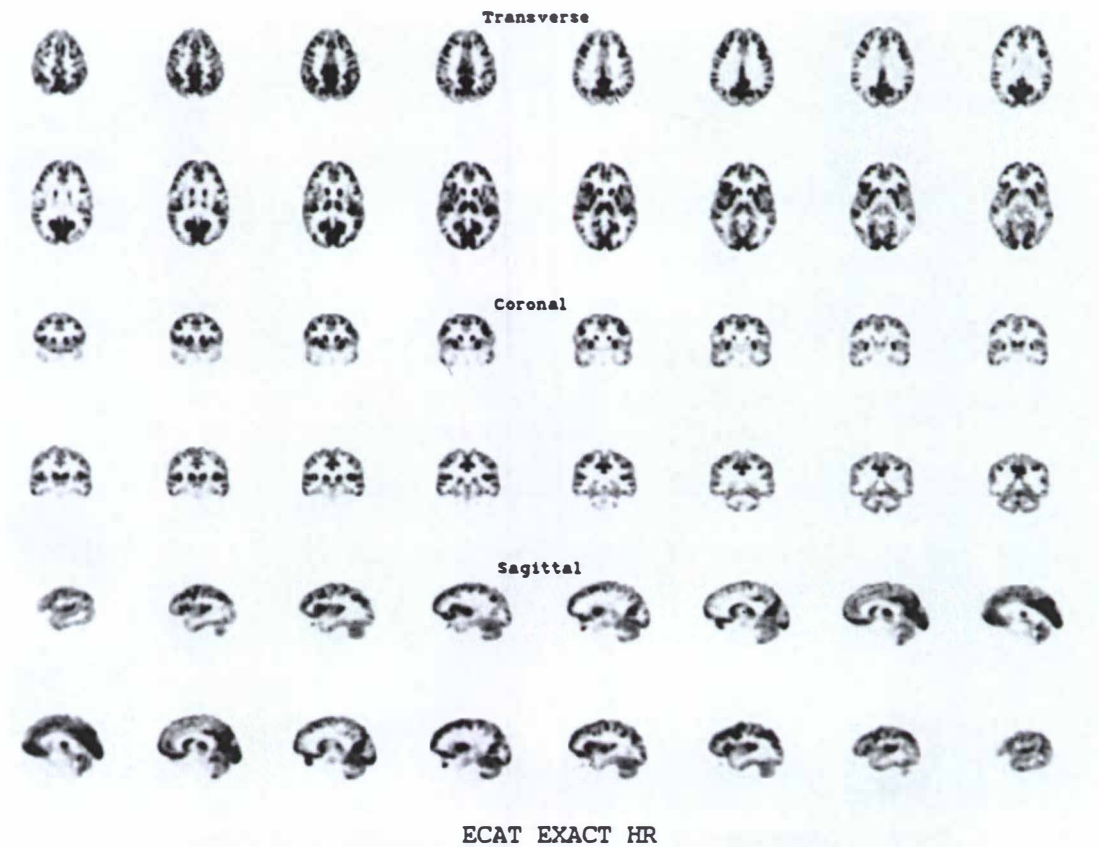
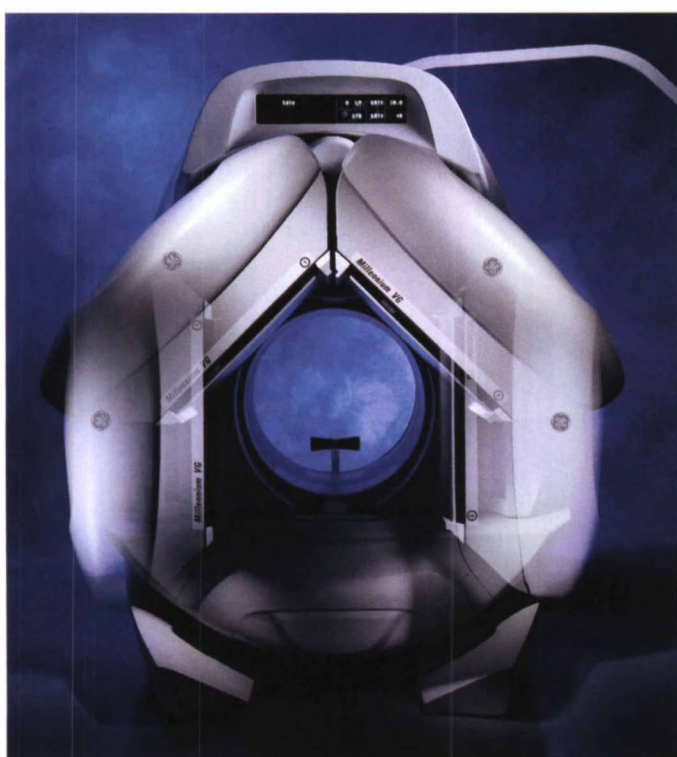


Fig. 38-13 Positron emission tomography (PET) brain study using fluorodeoxyglucose (FDG) to measure metabolic changes in the brain.



### COMBINED PET/CT AND SPECT/CT

Now there is available a blending of imaging function and form. By merging the functional imaging of PET and SPECT with the anatomical landmarks of CT more powerful diagnostic information is obtainable (Fig. 38-14). This combination will have a significant impact on diagnosing and staging malignant disease and on identifying and localizing metastases. This new technology will be used for both anatomical localization and attenuation correction. Manufacturers report that statistics are demonstrating that adding CT (both for attenuation correction and anatomical definition) changes the patient course of treatment 25% to 30% from what would have been done when using the functional image alone.



**Fig. 38-14** Combined SPECT/CT camera for a blending of imaging function and form.

(Courtesy of General Electric.)

## Clinical Nuclear Medicine

The term *in vivo* means “within the living body.” Because all diagnostic nuclear medicine imaging procedures are based on the distribution of radiopharmaceuticals within the body, they are classified as *in vivo* examinations.

Patient preparation for nuclear medicine procedures is minimal, with most tests requiring no special preparation. Patients usually remain in their own clothing. However, all metal objects outside or inside the clothing must be removed because they may mimic, or attenuate, pathologic conditions on nuclear medicine imaging. The waiting time between dose administration and imaging varies with each study. After completion of a routine procedure, patients may resume all normal activities.

Following are technical summaries of some of the more commonly performed nuclear medicine procedures. After each procedure summary is a list, by organ or system, of many common studies that may be done in an average nuclear medicine department.

### BONE SCINTIGRAPHY

Bone scintigraphy is generally a survey procedure to evaluate patients with malignancies, diffuse musculoskeletal symptoms, abnormal laboratory results, and hereditary or metabolic disorders. Tracer techniques have been used for many years to study the exchange between bone and blood. Radionuclides have played an important role in understanding both normal bone metabolism and the metabolic effects of pathologic involvement of bone. Radiopharmaceuticals used for bone imaging can localize in bone and also in soft tissue structures. Skeletal areas of increased uptake are commonly a result of tumor, infection, or fracture.

#### Bone scan

##### Principle

It is not entirely clear how  $^{99m}\text{Tc}$ -labeled diphosphonates are incorporated into bone at the molecular level; however, it appears that regional blood flow, osteoblastic activity, and extraction efficiency are the major factors that influence the uptake. In areas in which osteoblastic activity is increased, active hydroxyapatite crystals with large surface areas appear to be the most suitable sites for uptake of the diphosphonate portion of the radiopharmaceutical.

#### Radiopharmaceutical

The adult dose of 20 mCi (740 MBq) of  $^{99m}\text{Tc}$  hydroxymethylene diphosphonate (HDP) or 20 mCi (740 MBq) of  $^{99m}\text{Tc}$  methylene diphosphonate (MDP) is injected intravenously. The pediatric dose is adjusted according to the patient's weight.

#### Scanning

A routine survey begins 2 to 3 hours after the injection and takes 30 to 45 minutes. The number of camera images acquired depends on the indication for the examination.

#### Bone (skeletal) studies

Bone scan, bone marrow scan, and joint scan.

## NUCLEAR CARDIOLOGY

Nuclear cardiology has experienced rapid growth in recent years and currently composes a significant portion of daily nuclear medicine procedures. These noninvasive studies assess cardiac performance, evaluate myocardial perfusion, and measure viability and metabolism. Advances in computers and scintillation camera technology have facilitated the development of a quantitative cardiac evaluation unequaled by any other noninvasive or invasive methods. The stress test is performed with the patient using a treadmill or stationary bicycle. During the stress test the patient's heart rate, electrocardiogram (ECG or EKG), blood pressure, and symptoms are continuously monitored. Some patients cannot exercise because of peripheral vascular disease, neurologic problems, or musculoskeletal abnormalities. In these patients, a pharmacologic intervention can be used in place of the exercise test to alter the blood flow to the heart in a way that simulates exercise, allowing the detection of myocardial ischemia. Three procedures are discussed in the following sections.

### Exercise radionuclide angiography

#### Principle

Gated radionuclide angiography (RNA) can be used to measure left ventricular ejection fraction and evaluate left ventricular regional wall motion. RNA requires that the blood be labeled with an appropriate tracer such as  $^{99m}\text{Tc}$ . The technique is based on imaging using a multi-gated acquisition (MUGA) format. During a gated acquisition the cardiac cycle is divided into 16 to 20 frames. The R-wave of each cycle resets the gate so that each count is added to each frame, until there are adequate count statistics for analysis. RNA requires simultaneous acquisition of the patient's ECG and images of the left ventricle. The ejection fraction and wall motion analysis can be measured at rest and stress.

#### Radiopharmaceutical

The adult dose is 25 to 40 mCi (1110 MBq) of  $^{99m}\text{Tc}$ -labeled red blood cells, based on the patient's body surface area (i.e., height and weight). The pediatric dose is adjusted according to the patient's weight.

### Scanning

Imaging can begin immediately after the injection and takes about 1 hour. Imaging of the heart should be obtained in the anterior, left lateral, and left anterior oblique positions.

### $^{201}\text{Tl}$ myocardial perfusion study

#### Principle

The stress thallium-201 study has high sensitivity (about 90%) and specificity (about 75%) for the diagnosis of coronary artery disease. This study also has been useful for assessing myocardial viability in patients with known coronary artery disease and for evaluating patients after revascularization. At rest, symptoms may not be apparent.  $^{201}\text{Tl}$  is an analog of potassium and has a high rate of extraction by the myocardium over a wide range of metabolic and physiologic conditions.  $^{201}\text{Tl}$  is distributed in the myocardium in proportion to regional blood flow and myocardial cell viability. Under stress, myocardial  $^{201}\text{Tl}$  uptake peaks within 1 minute.  $^{201}\text{Tl}$  uptake in the heart ranges from about 1% of the injected dose at rest to about 4% with maximum exercise. Regions of the heart that are infarcted or underperfused at the time of injection appear as areas of decreased activity (photopenia).



### Radiopharmaceutical

The adult dose for a stress study is 3 mCi (111 MBq) of  $^{201}\text{Tl}$  thallous chloride administered intravenously at peak stress; 1 mCi (37 MBq) of  $^{201}\text{Tl}$  is administered intravenously before the delayed study, generally 3 to 4 hours after stress. The adult dose for a rest study is 4 mCi (148 MBq) of  $^{201}\text{Tl}$  administered intravenously before the rest study. The minimum dose recommended for pediatric patients is 300 mCi (11.1 MBq) of  $^{201}\text{Tl}$  thallous chloride. Whenever possible,  $^{99\text{m}}\text{Tc}$  sestamibi should be used in place of  $^{201}\text{Tl}$  in obese patients, so that a higher dose may be administered for clearer imaging results.

### Scanning

The images obtained include the anterior planar image of the chest and heart, followed by a 180-degree SPECT study (45 degrees right anterior oblique to 45 degrees left posterior oblique).

### $^{99\text{m}}\text{Tc}$ sestamibi myocardial perfusion study

#### Principle

Like  $^{201}\text{Tl}$ ,  $^{99\text{m}}\text{Tc}$  sestamibi is a cation; however, it has a slightly lower fractional extraction than thallium, particularly at high flow rates.  $^{99\text{m}}\text{Tc}$  sestamibi has favorable biologic properties for myocardial perfusion imaging. It is used to assess myocardial salvage resulting from therapeutic intervention in acute infarction, to determine the myocardial blood flow during periods of spontaneous chest pain, and to diagnose coronary artery disease in obese patients. A first-pass flow study can be performed with a rest or stress  $^{99\text{m}}\text{Tc}$  sestamibi myocardial perfusion scan. A first-pass study evaluates heart function, ejection fraction, during the short time (in seconds) that it takes the injected bolus to travel through the left ventricle.

### Radiopharmaceutical

The adult dose for the stress study is 10 to 30 mCi (370 to 1100 MBq) of  $^{99\text{m}}\text{Tc}$  sestamibi administered intravenously at peak stress. The adult dose for rest study is 10 to 30 mCi (370 to 1100 MBq) of  $^{99\text{m}}\text{Tc}$  sestamibi administered intravenously before the rest study.

### Scanning

SPECT imaging should normally be done 30 to 60 minutes after injection of the dose, for both stress and rest studies. When needed, more delayed images can be obtained for up to 4 to 6 hours after injection. A 2-day protocol provides optimum image quality, but the 1-day protocol is more convenient for patients, technologists, and physicians.

### Cardiovascular studies

Aortic/mitral regurgitant index, cardiac shunt study, dobutamine multiple gated acquisition (MUGA), rest MUGA, rest MUGA-ejection fraction only, exercise MUGA, stress testing (myocardial perfusion),  $^{201}\text{Tl}$  myocardial perfusion scan,  $^{99\text{m}}\text{Tc}$  sestamibi first-pass study,  $^{99\text{m}}\text{Tc}$  sestamibi myocardial perfusion scan,  $^{99\text{m}}\text{Tc}$  pyrophosphate (PYP) myocardial infarct scan, and rest  $^{201}\text{Tl}$  scan with infarct quantitation.

## CENTRAL NERVOUS SYSTEM

The central nervous system (CNS) consists of the brain and spinal cord. For patients with diseases of the central or peripheral nervous systems, nuclear medicine techniques can be used to assess the effectiveness of surgery or radiation therapy, document the extent of involvement of the brain by tumors, and determine progression or regression of lesions in response to different forms of treatment. Brain perfusion imaging is useful in the evaluation of patients with stroke, transient ischemia, and other neurologic disorders such as Alzheimer's disease, epilepsy, and Parkinson's disease. Radionuclide cisternography is particularly useful in the diagnosis of CSF leakage after trauma or surgery, and normal-pressure hydrocephalus. Recent studies indicate that documented lack of cerebral blood flow should be the criterion of choice to confirm brain death when clinical criteria are equivocal, when a complete neurologic examination cannot be performed, or when patients are younger than 1 year.

### Brain SPECT study

#### Principle

Some imaging agents are capable of penetrating the intact blood-brain barrier. After a radiopharmaceutical crosses the *blood-brain barrier*, it becomes trapped inside the brain. The regional uptake and retention of the tracer are related to the regional perfusion. Note that before the imaging agent is injected, the patient is placed in a quiet, darkened area and instructed to close the eyes. These measures are helpful in reducing uptake of the tracer in the visual cortex.

### Radiopharmaceutical

The adult dose is 20 mCi (740 MBq) of  $^{99\text{m}}\text{Tc}$  ethylcysteinate diamer (ECD) or  $^{99\text{m}}\text{Tc}$  hexamethylpropyleneamine-oxime (HMPAO). The pediatric dose is based on weight.

### Scanning

Imaging begins 30 minutes after  $^{99\text{m}}\text{Tc}$  ECD injection or 1 hour after  $^{99\text{m}}\text{Tc}$  HMPAO injection. Tomographic images of the brain are obtained.

### Central nervous system studies

Brain perfusion imaging—SPECT study, brain imaging—acetazolamide challenge study, CNS shunt patency, CSF imaging—cisternography/ventriculography,  $^{201}\text{Tl}$  scan for recurrent brain tumor, and  $^{99\text{m}}\text{Tc}$  HMPAO scan for determination of brain death.

## ENDOCRINE SYSTEM

The endocrine system organs, located throughout the body, secrete hormones into the bloodstream. Hormones have profound effects on overall body function and metabolism. The endocrine system consists of the thyroid, parathyroid, pituitary, and suprarenal glands, the islet cells of the pancreas, and the gonads. Nuclear medicine procedures have played a significant part in the current understanding of the function of the endocrine glands and their role in health and disease. These procedures are useful for monitoring treatment of endocrine disorders, especially in the thyroid gland. Thyroid imaging is performed to evaluate the size, shape, nodularity, and functional status of the thyroid gland. Imaging is used to screen for thyroid cancer and to differentiate hyperthyroidism, nodular goiter, solitary thyroid nodule, and thyroiditis.

### Thyroid scan

#### Principle

$^{99m}\text{Tc}$  pertechnetate or  $^{123}\text{I}$  can be used to image the thyroid gland.  $^{99m}\text{Tc}$  pertechnetate is trapped by the thyroid gland but, unlike iodine-131, is not organified into the gland. It offers the advantages of low radiation dose to the patient, no particulate radiation (unlike  $^{131}\text{I}$ ), and well-resolved images.  $^{123}\text{I}$  is organified into the gland. Imaging is used to determine the relative function in different regions within the thyroid, with special emphasis on the function of nodules compared to the rest of the gland. Scanning can also determine the presence and site of thyroid tissue in unusual areas of the body, such as the tongue and anterior chest (ectopic tissue).

#### Radiopharmaceutical

The adult dose is 5 mCi (185 MBq) of  $^{99m}\text{Tc}$  pertechnetate administered intravenously, or 0.5 to 1.5 mCi  $^{123}\text{I}$ . The pediatric dose is adjusted according to the patient's weight. Uptake may be affected by thyroid medication and by foods or drugs, including some iodine-containing contrast agents used for renal radiographic imaging and CT scanning.

#### Scanning

Scanning should start 20 minutes after the injection. A gamma camera with a pinhole collimator is used to obtain anterior, left oblique, and right anterior oblique thyroid images and a 6-inch (15-cm) anterior neck image. The pinhole collimator is a thick, conical collimator that allows for magnification of the thyroid.

### $^{131}\text{I}$ thyroid uptake measurement

#### Principle

Radioiodine is concentrated by the thyroid gland in a manner that reflects the ability of the gland to handle stable dietary iodine. Therefore  $^{131}\text{I}$  uptake is used to estimate the function of the thyroid gland by measuring its avidity for administered radioiodine. The higher the uptake of  $^{131}\text{I}$ , the more active the thyroid; conversely, the lower the uptake, the less functional the gland. Uptake conventionally is expressed as the percentage of the dose in the thyroid gland at a given time after administration.  $^{131}\text{I}$  uptake measurement is of value in distinguishing between thyroiditis (reduced uptake) and Graves' disease or toxic nodular goiter (Plummer's disease), which has an increased uptake. It is also used to determine the appropriateness of a therapeutic dose of  $^{131}\text{I}$  in patients with Graves' disease, residual or recurrent thyroid carcinoma, or thyroid remnant after thyroidectomy.

#### Radiopharmaceutical

All doses of  $^{131}\text{I}$  sodium iodide are administered orally. The adult dose for a standard uptake test is 3 to 5  $\mu\text{Ci}$  (148 to 222 kBq) of  $^{131}\text{I}$ . The pediatric dose is adjusted according to the patient's weight. A standard dose is counted with the thyroid probe, in the morning of the scan, and is used as 100% of maximum counts. The patient's total count is compared to the standard counts to obtain the patient percent uptake.

Measurements are obtained using an uptake probe consisting of a  $2 \times 2$  inch ( $5 \times 5$  cm) sodium iodide/photomultiplier tube assembly fitted with a flat-field lead collimator (Fig. 38-15). Uptake readings are acquired at 4 or 6 hours and/or at 24 hours.



Fig. 38-15 Uptake probe used for thyroid uptake measurements over the extended neck area.



**Neck/total-body  $^{131}\text{I}$  scan****Principle**

A neck or total-body  $^{131}\text{I}$  scan is recommended for locating residual thyroid tissue or recurrent thyroid cancer cells in patients with thyroid carcinoma. Most follicular or papillary thyroid cancers concentrate radioiodine; other types of thyroid cancer do not. A neck scan is usually performed 1 to 3 months after a thyroidectomy to check for residual normal thyroid tissue. After the residual thyroid tissue has been ablated (destroyed), a total-body  $^{131}\text{I}$  scan is performed to check for the metastatic spread of the cancer.

**Radiopharmaceutical**

The adult dose for a total-body  $^{131}\text{I}$  scan is generally 3 mCi (111 MBq) of  $^{131}\text{I}$  sodium iodide administered orally. The adult dose for a neck scan is 1 mCi (37 MBq) of  $^{131}\text{I}$  sodium iodide administered orally. Thyrogen may be injected on each of two days before dose administration. This allows the patient to remain on thyroid medications. The pediatric dose is adjusted according to the patient's weight.

**Scanning**

Neck imaging starts 24 hours after administration of the dose. Total-body imaging begins 48 hours after dose administration. Images are obtained of the anterior planar neck. Total-body images are of the anterior and posterior whole body.

**Endocrine studies**

Adrenal cortical scan (NP-59), adrenal medullary scan (mIBG), ectopic thyroid scan ( $^{131}\text{I}/^{123}\text{I}$ ), thyroid scan ( $^{99\text{m}}\text{Tc}$  pertechnetate),  $^{131}\text{I}$  thyroid uptake measurement,  $^{123}\text{I}$  thyroid uptake/scan,  $^{131}\text{I}$  neck/total body iodine scan, parathyroid scan, indium-111 pentetreotide scan.

**GASTROINTESTINAL SYSTEM**

The gastrointestinal system, or alimentary canal, consists of the mouth, oropharynx, esophagus, stomach, small bowel, colon, and several accessory organs (salivary glands, pancreas, liver, and gallbladder). The liver is the largest internal organ of the body. The portal venous system brings blood from the stomach, bowel, spleen, and pancreas to the liver.

**Liver/spleen scan****Principle**

Liver and/or spleen scanning is used to evaluate the liver for functional disease (e.g., cirrhosis, hepatitis, metastatic disease) and to look for residual splenic tissue following splenectomy. Imaging techniques such as ultrasonography, CT, and MRI provide excellent information about the anatomy of the liver, but nuclear medicine studies can assess the *functional* status of this organ. Liver and spleen scintigraphy is also useful for detecting hepatic lesions, and evaluating hepatic morphology and function. It is also used to determine whether certain lesions found with other methods may be benign (e.g., focal nodular hyperplasia), thereby obviating the need for biopsy. Uptake of a radiopharmaceutical in the liver, spleen, and bone marrow depends on blood flow and the functional capacity of the phagocytic cells. In normal patients, 80% to 90% of the radiopharmaceutical is localized in the liver, 5% to 10% in the spleen, and the rest in the bone marrow.

**Radiopharmaceutical**

Adults receive 6 mCi (222 MBq) of  $^{99\text{m}}\text{Tc}$  sulfur colloid or  $^{99\text{m}}\text{Tc}$  albumin colloid injected intravenously. The pediatric dose is adjusted according to the patient's weight.

**Scanning**

Images obtained may be planar standard (anterior, posterior, right and left anterior oblique, right and left lateral, right posterior oblique, and a marker view), life-size, or SPECT.

**Gastrointestinal studies**

Anorectal angle study, colonic transit study, colorectal/neorectal emptying study, esophageal scintigraphy, gastroesophageal reflux (adults and children) study, gastric emptying study, small-bowel transit study, hepatic artery perfusion scan, hepatobiliary scan, hepatobiliary scan with gallbladder ejection fraction, evaluation of human serum albumin for protein-losing gastroenteropathy, liver/spleen scan, liver hemangioma study, Meckel's diverticulum scan, salivary gland study.

**GENITOURINARY NUCLEAR MEDICINE**

Genitourinary nuclear medicine studies are recognized as reliable, noninvasive procedures for evaluating the anatomy and function of the systems in nephrology, urology, and kidney transplantation. These studies can be accomplished with minimum risk of allergic reactions, unpleasant side effects, or excessive radiation exposure to the organs.

**Dynamic renal scan****Principle**

Renal scanning is used to assess renal perfusion and function, particularly in renal failure and renovascular hypertension and after renal transplantation.  $^{99\text{m}}\text{Tc}$  mertiatide (MAG3) is secreted primarily by the proximal renal tubules, and is not retained in the parenchyma of normal kidneys.

**Radiopharmaceutical**

The adult dose is 10 mCi (370 MBq) of  $^{99\text{m}}\text{Tc}$  MAG3. The pediatric dose is adjusted according to the patient's weight.

**Scanning**

Imaging is initiated immediately after the injection. Because radiographic contrast media may interfere with kidney function, renal scanning should be delayed for 24 hours after contrast studies. Images are often taken over the posterior lower back, centered at the level of the twelfth rib. Transplanted kidneys are imaged in the anterior pelvis. Patients need to be well hydrated, determined by a specific gravity test, before all renal studies.

**Genitourinary studies**

Dynamic renal scan, dynamic renal scan with furosemide, dynamic renal scan with captopril, pediatric furosemide renal scan,  $^{99\text{m}}\text{Tc}$  dimercaptosuccinic acid (DMSA) renal scan, residual urine determination, testicular scan, voiding cystography.



## IN VITRO AND IN VIVO HEMATOLOGIC STUDIES

In vitro and in vivo hematologic studies have been performed in nuclear medicine for many years. Quantitative measurements are made after a radiopharmaceutical has been administered, often at predetermined intervals. The two types of nonimaging nuclear medicine procedures are as follows:

- *In vitro* radioimmunoassay for quantitating biologically important substances in the serum or other body fluids.
- *In vivo* evaluation of physiologic function by administering small tracer amounts of radioactive materials to the patient and subsequently counting specimens of urine, blood, feces, or breath. A wide variety of physiologic events may be measured, including vitamin B<sub>12</sub> absorption (Schilling test), red cell survival and sequestration, red cell mass, plasma volume.

### Hematologic studies

Plasma volume measurement, Schilling test, red cell mass, red cell survival, red cell sequestration.

## IMAGING FOR INFECTION

Imaging for infection is another useful nuclear medicine diagnostic tool. Inflammation, infection, and abscess may be found in any organ or tissue and at any location within the body. Imaging procedures such as gallium-67 scans, and <sup>111</sup>In-labeled white cell scans are both useful for diagnosis and localization of infection and inflammation.

### Infection studies

<sup>67</sup>Ga gallium scan, <sup>111</sup>In white blood cell scans, <sup>99m</sup>Tc HMPAO, and post total hip or knee replacement surgery.

## RESPIRATORY IMAGING

Respiratory imaging commonly involves the demonstration of pulmonary perfusion using limited, transient capillary blockade and the assessment of ventilation using an inhaled radioactive gas or aerosol. Lung imaging is most commonly performed to evaluate pulmonary emboli, chronic obstructive pulmonary disease, chronic bronchitis, emphysema, asthma, and lung carcinoma. It is also used for lung transplant evaluation.

### <sup>133</sup>Xe lung ventilation scan

#### Principle

Lung ventilation scans are used in combination with lung perfusion scans. The gas used for a ventilation study must be absorbed significantly by the lungs and diffuse easily. Xenon-133 has adequate imaging properties, and the body usually absorbs less than 15% of the gas.

#### Radiopharmaceutical

The adult dose is 15 to 30 mCi (555 to 1,110 MBq) of <sup>133</sup>Xe gas administered by inhalation.

#### Scanning

Imaging starts immediately after inhalation of the xenon gas begins in a closed system to which oxygen is added and carbon dioxide is withdrawn. When <sup>133</sup>Xe gas is used, the ventilation study must precede the <sup>99m</sup>Tc perfusion scan. Posterior and anterior images are obtained for the first breath equilibrium, and *washout*. If possible, left and right posterior oblique images should be obtained between the first breath and equilibrium.

### <sup>99m</sup>Tc macroaggregated albumin lung perfusion scan

#### Radiopharmaceutical

The adult dose is 4 mCi (148 MBq) of <sup>99m</sup>Tc MAA. The pediatric dose is adjusted according to the patient's weight.

#### Scanning

Imaging starts 5 minutes after the injection. Eight images should be obtained: anterior, posterior, right and left lateral, right and left anterior oblique, and right and left posterior oblique. The nuclear medicine physician may need additional images. All patients should have a chest radiograph within 24 hours of the lung scan. The chest radiograph is required for accurate interpretation of the lung scans, to determine the probability for pulmonary embolism.

### Respiratory studies

<sup>99m</sup>Tc DTPA lung aerosol scan, <sup>99m</sup>Tc MAA lung perfusion scan, <sup>133</sup>Xe lung ventilation scan.

## THERAPEUTIC NUCLEAR MEDICINE

The potential that radionuclides have for detecting and treating cancer has been recognized for decades. Radioiodine is a treatment in practically all adults with Graves' disease, except those who are pregnant or breast-feeding. High-dose <sup>131</sup>I therapy (30 mCi or more) is used in patients with residual thyroid cancer or thyroid metastases. Phosphorus-32 in the form of sodium phosphate can be used to treat polycythemia, a disease characterized by the increased production of red blood cells. <sup>32</sup>P chromic phosphate colloid administered into the peritoneal cavity is useful in the postoperative management of ovarian and endometrial cancers because of its effectiveness in destroying many of the malignant cells remaining in the peritoneum. Skeletal metastases occur in more than 50% of patients with breast, lung, or prostate cancer in the end stages of the disease. Strontium-99 is often useful for managing patients with bone pain from metastases when other treatments have failed.

### Therapeutic procedures

<sup>131</sup>I therapy for hyperthyroidism and thyroid cancer, <sup>32</sup>P therapy for polycythemia, <sup>32</sup>P intraperitoneal therapy, <sup>32</sup>P intrapleural therapy, <sup>89</sup>Sr bone therapy.

## SPECIAL IMAGING PROCEDURES

Special imaging procedures include dacryoscintigraphy, LeVeen shunt patency test, sentinel node studies for melanoma or breast cancer, and lymphoscintigraphy of the limbs.

## TUMOR STUDIES

<sup>67</sup>Ga tumor scan, <sup>99m</sup>Tc sestamibi breast scan, <sup>111</sup>In OncoScint (satumomab pendetide) scan, <sup>111</sup>In ProstaScint (capromab pendetide) scan, <sup>99m</sup>Tc CEA gastrointestinal scan, <sup>99m</sup>Tc verluma for small cell lung cancer and <sup>111</sup>In Octreoscan.

## Bone Mineral Density

Information on bone mineral loss is clinically important for the monitoring of age-related bone loss, the diagnosis and monitoring of bone loss resulting from metabolic bone disease, the assessment of drug effects on bone mineralization, and the accurate assessment of fracture risk at specific sites. An awareness of bone density is important because *osteoporosis* (severe progressive bone loss) affects more than 20 million women and 5 million men in the United States. Women experience normal bone loss after menopause as a result of a decrease in estrogen. Osteoporosis may not have symptoms because it is a progressive disease. The decrease in bone density is gradual and can lead to fractures of the hip, spine, or wrist. The broken bones result in pain, height loss, difficulty in mobility, a deformed backbone that curves forward (sometimes called "dowager's hump"), and possibly permanent disability and dependence. Hip fracture is responsible for considerable mortality in the elderly. (See Chapter 39 for a more complete description of bone mineral densitometry.)

Measurements may be performed to assess cortical or trabecular bone mineral loss resulting from accelerated bone resorption or decreased bone formation, to predict total body calcium, and to provide a quantitative result that can be used as a predictor of fracture risk.

Several types of devices are available for the measurement of bone density; all are painless, noninvasive, and safe (Fig. 38-16). *Dual-energy x-ray absorptiometry (DXA)* is the diagnostic method currently preferred by many experts because it provides the best resolution and reproducibility. Bone mineral analysis studies are done on the spine, hip, or wrist, the most common sites of osteoporosis-related fractures, and occasionally on the whole body. Measurements are compared with expected values for populations of the patient's age, sex, and size and with the estimated peak bone density of a healthy young adult of the same sex. Routine radiographs are not sensitive enough to detect osteoporosis until 25% to 40% of bone mass has been lost and the disease is well advanced.

The most common bone density measurement techniques are as follows:

- DXA, also known as *DEXA*, is the most accurate and advanced technique. A focused x-ray beam is used to scan in a rectilinear fashion and to record separate low- and high-energy transmitted photon energy values through the bone. The study is based on the principle that normal, healthy bone containing adequate mineral blocks x-ray better than weak, undermineralized bone. DXA scans of the hip and spine take 5 to 15 minutes.
- Dual photon absorptiometry (DPA), an earlier generation of DXA, is now in limited use.
- Single-energy x-ray absorptiometry (SXA) uses a very low-dose x-ray source and measures bone in the wrist or heel. Single photon absorptiometry (SPA) is an earlier version of SXA.
- Quantitative computed tomography (QCT) uses a conventional CT scanner with special computer software. Although QCT provides an effective measurement of the spine, it emits a higher radiation dose than DXA and is usually more costly.
- Radiographic absorptiometry (RA) uses a specialized x-ray technique of the hand to calculate bone density.

The total-body method is the fastest growing area of densitometry in the United States and worldwide. The increasing interest in body composition, pediatric applications, and sports medicine has been a strong factor in this growth. Densitometer sales have been continuous during the past few years, with about half of these devices being installed in radiology practices. The introduction of new drugs for the treatment of osteoporosis has also increased the demand for patient studies.

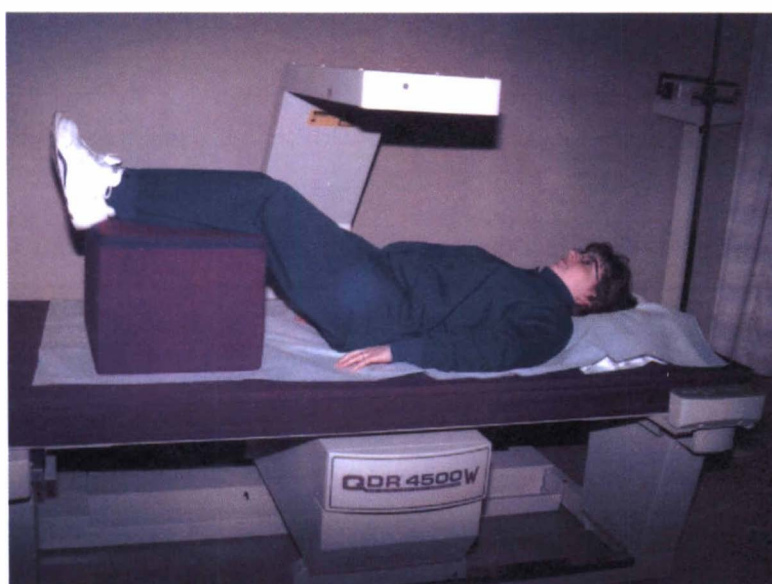


Fig. 38-16 Bone mineral measurements are painless, noninvasive, and safe.



## Conclusion

Nuclear medicine technology is a multidisciplinary field in which medicine is linked to quantitative sciences, including chemistry, radiation biology, physics, and computer technology. During the past 100 years, nuclear medicine has expanded to include molecular nuclear medicine, in vivo and in vitro chemistry, and physiology. The spectrum of nuclear medicine technology skills and responsibilities varies. The scope of nuclear medicine technology includes patient care, quality control, diagnostic procedures, computer data acquisition and processing, radiopharmaceuticals, radionuclide therapy, and radiation safety. Many clinical procedures currently are performed in nuclear medicine departments across the country and throughout the world. Nuclear medicine procedures complement other imaging methods in radiology and pathology departments.

The future of nuclear medicine may lie in its unique ability to identify functional or physiologic abnormalities. With the continued development of new radiopharmaceuticals and imaging technology, nuclear medicine will continue to be a unique and valuable tool for diagnosing and treating disease.

## Definition of Terms

**alpha particle** Nucleus of a helium atom, consisting of 2 protons and 2 neutrons, having a positive charge of 2.

**atom** Smallest division of an element that exhibits all the properties and characteristics of the element; composed of neutrons, electrons, and protons.

**becquerel (Bq)** Unit of activity in the International System of Units; equal to one disintegration per second (dps): 1 Bq=1 dps.

**beta particle** Electron whose point of origin is the nucleus; electron originating in the nucleus by way of decay of a neutron into a proton and an electron.

**blood-brain barrier** Anatomic and physiologic feature of the brain thought to consist of walls of capillaries in the CNS and surrounding glial membranes. The barrier separates the parenchyma of the central nervous system from blood. The blood-brain barrier prevents or slows the passage of some drugs and other chemical compounds, radioactive ions, and disease-causing organisms such as viruses from the blood into the CNS.

**cold spot** Lack of radiation being received or recorded, thus not producing any image and resulting in an area of no, or very light, density. May be caused by disease or artifact.

**collimator** Shielding device used to limit the angle of entry of radiation; usually made of lead.

**curie** Standard of measurement for radioactive decay; based on the disintegration of 1 gram of radium at  $3.7310^{10}$  disintegrations per second.

**cyclotron** Device for accelerating charged particles to high energies using magnetic and oscillating electrostatic fields. As a result, particles move in a spiral path with increasing energy.

**daughter** Element that results from the radioactive decay of a parent element.

**decay** Radioactive disintegration of the nucleus of an unstable nuclide.

**dual-energy x-ray absorptiometry (DXA)** Currently the most accurate and advanced technique for measuring bone mineral density. It uses a very small dose of radiation emitted through a highly focused beam.

**electron** Negatively charged elementary particle that has a specific charge, mass, and spin.

**electron capture** Radioactive decay process in which a nucleus with an excess of protons brings an electron into the nucleus, creating a neutron out of a proton, thus decreasing the atomic number by 1. The resulting atom is often unstable and gives off a gamma ray to achieve stability.

**external radiation detector** Instrument used to determine the presence of radioactivity from the exterior.



**fission** Splitting of a nucleus into two or more parts with the subsequent release of enormous amounts of energy.

**gamma camera** Device that uses the emission of light from a crystal struck by gamma rays to produce an image of the distribution of radioactive material in a body organ.

**gamma ray** High-energy, short-wave-length electromagnetic radiation emanating from the nucleus of some nuclides.

**ground state** State of lowest energy of a system.

**half-life ( $T_{1/2}$ )** Term used to describe the time elapsed until some physical quantity has decreased to half of its original value.

**in vitro** Outside a living organism.

**in vivo** Within a living organism.

**isotope** Nuclide of the same element with the same number of protons but a different number of neutrons.

**light pipe** A tubelike structure attached to the scintillation crystal to convey the emitted light to the photomultiplier tube.

**metastable** Describes the excited state of a nucleus that returns to its ground state by emission of a gamma ray; has a measurable lifetime.

**neutron** Electrically neutral particle found in the nucleus; has a mass of 1 mass unit.

**nuclear reactor** Device that under controlled conditions is used for supporting a self-sustained nuclear reaction.

**nuclide** General term applicable to all atomic forms of an element.

**parent** Radionuclide that decays to a specific daughter nuclide either directly or as a member of a radioactive series.

**particle accelerator** Device that provides the energy necessary to enable a nuclear reaction.

**pharmaceutical** Relating to a medicinal drug.

**photomultiplier tube** Electronic tube that converts light photons to electric pulses.

**photopenia** Lack of radiation being received or recorded, thus not producing any image and resulting in an area of no, or very light, density. May be caused by disease or artifact.

**proton** Positively charged particle that is a fundamental component of the nucleus of all atoms. The number of protons in the nucleus of an atom equals the atomic number of the element.

**pulse height analyzer** Instrument that accepts input from a detector and categorizes the pulses on the basis of signal strength.

**pyrogen free** Free of a fever-producing agent of bacterial origin.

**radiation** Emission of energy; rays of waves.

**radioactive** Exhibiting the property of spontaneously emitting alpha, beta, and gamma rays by disintegration of the nucleus.

**radioactivity** Spontaneous disintegration of an unstable atomic nucleus resulting in the emission of ionizing radiation.

**radionuclide** Unstable nucleus that transmutes by way of nuclear decay.

**radiopharmaceutical** Refers to a radioactive drug used for diagnosis or therapy.

**rectilinear scanner** Early imaging device that passed over the area of interest, moving in or forming a straight line.

**scintillate** To emit light photons.

**scintillation camera** See *gamma camera*.

**scintillation detector** Device that relies on the emission of light from a crystal subjected to ionizing radiation. The light is detected by a photomultiplier tube and converted to an electronic signal that can be processed further. An array of scintillation detectors are used in a gamma camera.

**single photon emission tomography (SPECT)** A nuclear medicine scanning procedure that measures conventional single photon gamma emissions ( $^{99m}\text{Tc}$ ) with a specially designed rotating gamma camera.

**tracer** A radioactive isotope used to allow a biologic process to be seen. The tracer is introduced into the body, binds with a specific substance, and is followed by a scanner as it passes through various organs or systems in the body.

**washout** The end of the radionuclide procedure, during which time the radioactivity is eliminated from the body.

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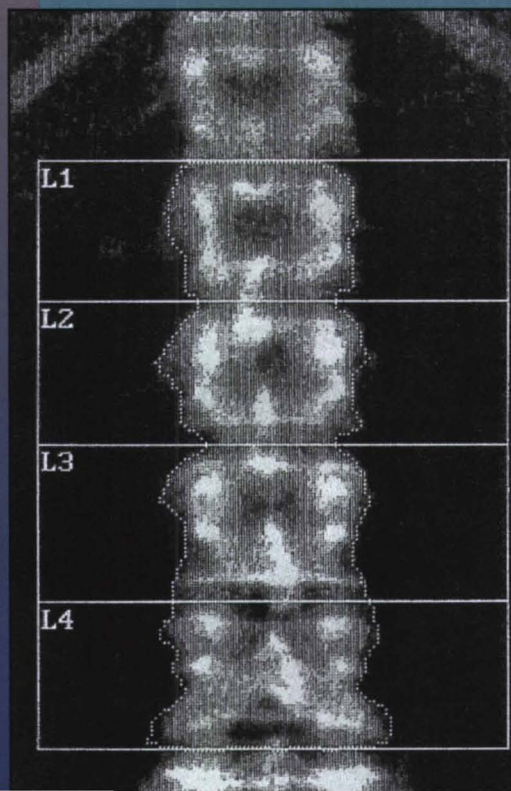


39

# BONE DENSITOMETRY

BARBARA A. BLUNT

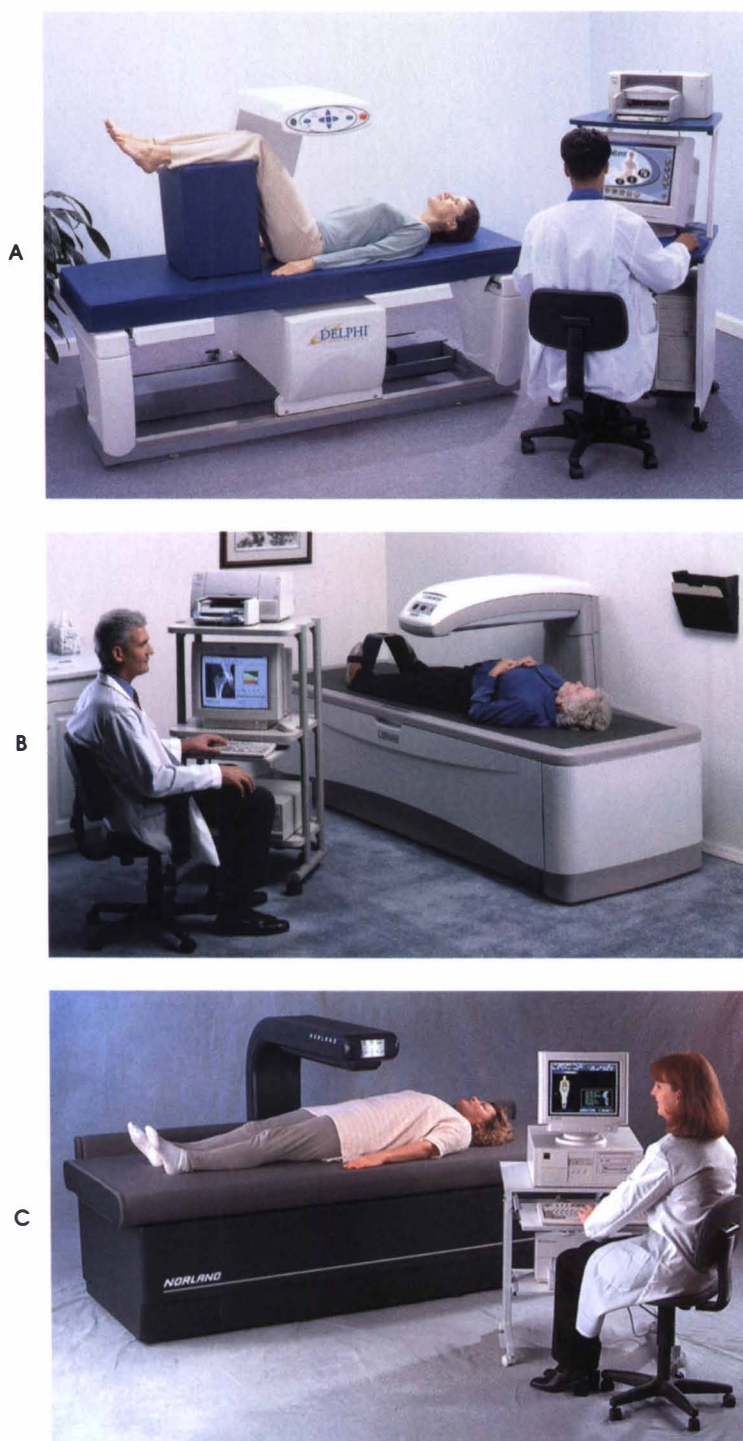
Dual energy x-ray absorptrometry (DXA) spine scan of the lumbar spine.



## OUTLINE

Principles of bone densitometry, 488  
History of bone densitometry, 489  
Bone biology and remodeling, 491  
Osteoporosis, 494  
Physical and mathematical principles of dual energy x-ray absorptiometry, 498  
Pencil-beam versus array-beam, 501  
Dual energy x-ray absorptiometry scanning, 508  
Other bone densitometry techniques, 522  
Summary, 528  
Definition of terms, 528  
Resources for information and instruction, 530





**Fig. 39-1** **A**, DXA spine scan being performed on a Hologic model Delphi. **B**, DXA hip scan being performed on a Lunar model Prodigy. **C**, DXA whole-body scan being performed on a Norland model XR-46.

(**A**, Courtesy Hologic, Inc., Bedford, Mass.; **B**, Courtesy GE-Lunar Corp., Madison, Wis.; **C**, Courtesy Norland, Inc., Ft. Atkinson, Wis.)

## Principles of Bone Densitometry

*Bone densitometry*\* is a general term encompassing the art and science of measuring the bone mineral content and density of specific skeletal sites or the whole body. The bone measurement values are used to assess bone strength, diagnose diseases associated with low bone density (especially *osteoporosis*), monitor the effects of therapy for such diseases, and predict risk of future fractures.

Several techniques are available to perform bone densitometry using ionizing radiation or ultrasound. The most versatile and widely used technique is *dual energy x-ray absorptiometry (DXA)* (Fig. 39-1).<sup>1</sup> This technique has the advantages of low radiation dose, wide availability, ease of use, short scan time, high-resolution images, good *precision*, and stable calibration. DXA is the focus of this chapter, but summaries of other techniques are also presented.

\*Almost all italicized words on the succeeding pages are defined at the end of this chapter.

<sup>1</sup>Gowin W, Felsenberg D: Acronyms in osteodensitometry, *J Clin Densitometry* 1:137, 1998.



## DUAL X-RAY ABSORPTIOMETRY AND CONVENTIONAL RADIOGRAPHY

The differences between DXA and conventional radiography are as follows:

1. DXA can be conceptualized as a *subtraction technique*. To quantitate *bone mineral density (BMD)* it is necessary to eliminate the contributions of soft tissue and measure the x-ray attenuation of bone alone. This is accomplished by scanning at two different x-ray photon energies (thus the term *dual energy x-ray*) and mathematically manipulating the recorded signal to take advantage of the differing attenuation properties of soft tissue and bone at the two energies. The density of the isolated bone is calculated based on the principle that denser, more mineralized bone attenuates (absorbs) more x-ray. It is essential to have adequate amounts of artifact-free soft tissue to help ensure the reliability of the bone density results.
2. The bone density results are computed by proprietary software from the x-ray attenuation pattern striking the detector, not from the scan image. DXA scans provide images only for the purpose of confirming correct positioning of the patient and correct placement of the *regions of interest (ROI)*. Therefore the images may not be used for diagnosis and any medical conditions apparent on the image must be followed-up by appropriate diagnostic tests. The referring and interpreting physicians must be skilled in interpreting the clinical and statistical aspects of the numeric density results and relating them to the specific patient.
3. In conventional radiography, x-ray machines from different manufacturers are operated in essentially the same manner and produce identical images. This is not the case with DXA. There are three major DXA manufacturers in the United States (see Fig. 39-1), and technologists must be educated for the specific scanner model in their facility. The numeric bone density results cannot be compared among manufacturers without proper standardization. This chapter presents general scan positioning and analysis information, but the manufacturers' specific procedures must be used when actual scans are performed.
4. The effective radiation dose for DXA is considerably lower than that for conventional radiography. Thus, in some states and countries, scanning can be performed by personnel who are not radiologic technologists. The specific personnel requirements vary among states and countries. However, all bone density technologists should be instructed in core competencies, including radiation protection, patient care, history taking, basic computer operation, knowledge of scanner quality control, patient positioning, scan acquisition and analysis, and proper record keeping and documentation.

## History of Bone Densitometry

Osteoporosis was an undetected and overlooked disease until the 1920s when the advent of x-ray film methods allowed the detection of markedly decreased density in bones. The first publications indicating an interest in *bone mass* quantification methods appeared in the 1930s, and much of the pioneering work was performed in the field of dentistry. *Radiographic absorptiometry (RA)* involved taking a radiograph of bone with a known standard placed in the field and optically comparing the densities. Interestingly, this technique has again gained popularity, with the comparison now automated by computer methods.

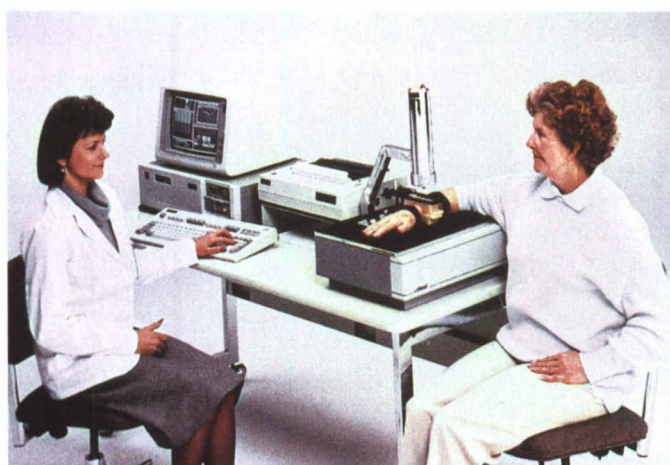
*Radiogammetry* was introduced in the 1960s, partly in response to the measurements of bone loss performed in astronauts. It is known that as bone loss progresses, the thickness of the outer shell of the small tubular bones (e.g., phalanges and metacarpals) decreases and the inner cavity enlarges. By measuring the inner and outer diameters and comparing them, indices of bone loss are established.

In the late 1970s, the emerging technique of computed tomography (CT) (see Chapter 33) was adapted, through the use of specialized software and reference phantoms, for quantitative measurement of the central area of the vertebral body, where early bone loss occurs. This technique, called *quantitative computed tomography (QCT)*, is still widely used.

The 1970s and early 1980s brought the first scanners dedicated to bone densitometry. *Single photon absorptiometry (SPA)* (Fig. 39-2) and *dual photon absorptiometry (DPA)* are based on physical principles similar to those for DXA. The SPA approach was not a subtraction technique but relied on a water bath or other medium to eliminate the effects of soft tissue. It found application only in the peripheral skeleton. DPA used photons of two energies and was used to assess sites in the central skeleton (lumbar spine and proximal femur). The radiation source was a highly collimated beam from a radioisotope, usually iodine-125 for SPA and gadolinium-153 for DPA. The intensity of the attenuated beam was measured by a collimated *scintillation counter* and the bone mineral was then quantified.

The first commercial DXA scanner was introduced in 1987. In this scanner the expensive, rare, and short-lived radioisotope source was replaced with an x-ray tube. Improvements over time have included the choice of *pencil-beam* or *array-beam collimation*, a rotating C-arm to allow supine lateral spine imaging, shorter scan time, improved detection of low bone density, improved image quality, and enhanced computer power, multimedia, and networking capabilities.

Since the late 1990s renewed attention has been given to smaller, more portable, less complex techniques for measuring the peripheral skeleton. This trend has been driven by the introduction of new therapies for osteoporosis and the resultant need for simple, inexpensive tests to identify persons with osteoporosis who are at increased risk for fracture. However, DXA of the hip and spine is still the most widely accepted method for measuring bone density, and it remains a superior technique for monitoring the effects of therapy.



**Fig. 39-2** SPA wrist scan being performed on a Lunar model SP2. This form of bone densitometry is now obsolete.

(Courtesy GE-Lunar Corp., Madison, Wis.)

## Bone Biology and Remodeling

The skeleton serves several purposes:

- Supports the body and protects vital organs so that movement, communication, and life processes can be carried on
- Manufactures red blood cells
- Stores the minerals that are necessary for life, including calcium and phosphate

The two basic types of bone are *cortical* (or compact) and *trabecular* (or cancellous). Cortical bone forms the dense, compact outer shell of all bones, as well as the shafts of the long bones. It supports weight, resists bending and twisting, and accounts for about 80% of the skeletal mass. Trabecular bone is the delicate, lattice-work structure within bones that adds strength without excessive weight. It supports compressive loading in the spine, hip, and calcaneus, and it is also found at the ends of long bones such as the distal radius. The relative amounts of trabecular and cortical bone differ by bone densitometry technique used and anatomical site measured (Table 39-1).

**TABLE 39-1**

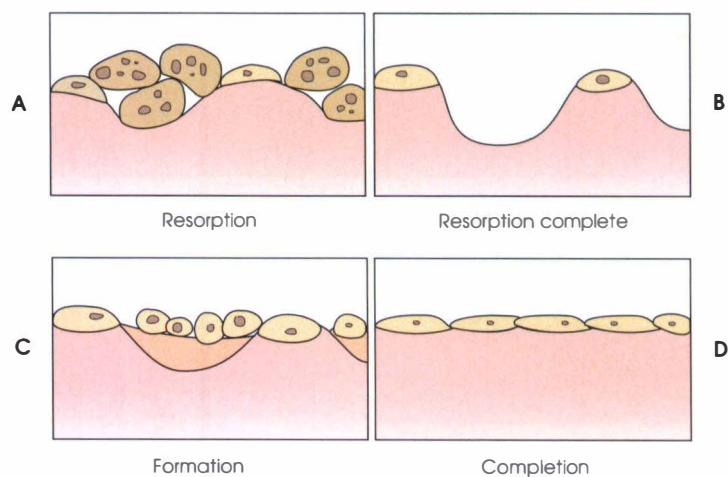
Bone densitometry regions of interest: estimated percent of trabecular and cortical bone and preferred measurement sites

Region of interest	% Trabecular bone	% Cortical bone	Preferred measurement site
AP Spine (by DXA)	66	34	Cushing's disease, corticosteroid use Type I osteoporosis if under age 65
AP Spine (by QCT)	100		
Femoral neck	25	75	Type II osteoporosis Second choice for hyperparathyroidism
Trochanteric region	50	50	
Calcaneus	95	5	
33% radius	1	99	First choice for hyperparathyroidism
Ultradistal radius	66	34	
Phalanges	40	60	
Whole body	20	80	Pediatrics

Data from Bonnick SL: *Bone densitometry in clinical practice: application and interpretation*, Totowa, NJ, 1998, Humana Press.



Bone is constantly going through a remodeling process in which old bone is replaced with new bone. With this *bone remodeling* process (Fig. 39-3) the equivalent of a new skeleton is formed about every 7 years. Bone-destroying cells called *osteoclasts* break down and remove old bone, leaving pits. This part of the process is called *resorption*. Bone-building cells called *osteoblasts* (tip: remember “B” for “build”) fill the pits with new bone. This process is called *formation*. The comparative rates of resorption and formation determine whether bone mass increases (more formation than resorption), remains stable (equal resorption and formation), or decreases (more resorption than formation).



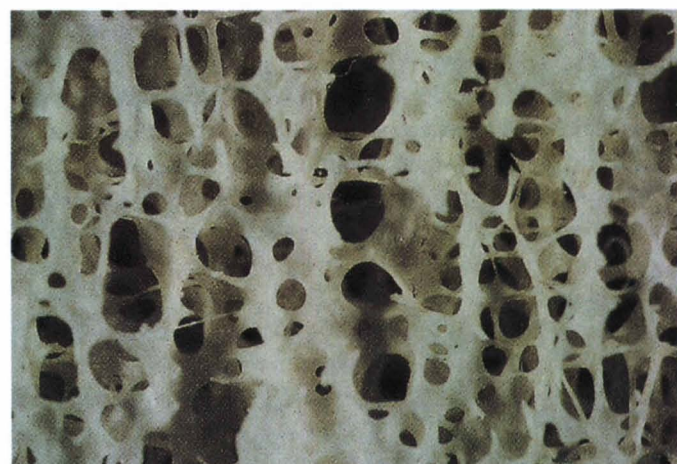
**Fig. 39-3** The bone remodeling process. **A**, Osteoclasts break down bone in the process of resorption. **B**, Pits in the bone. **C**, Osteoblasts form new bone. **D**, With equal amounts of resorption and formation, the bone mass is stable.

(From *Boning up on osteoporosis*, Washington, D.C., 1997, National Osteoporosis Foundation.)

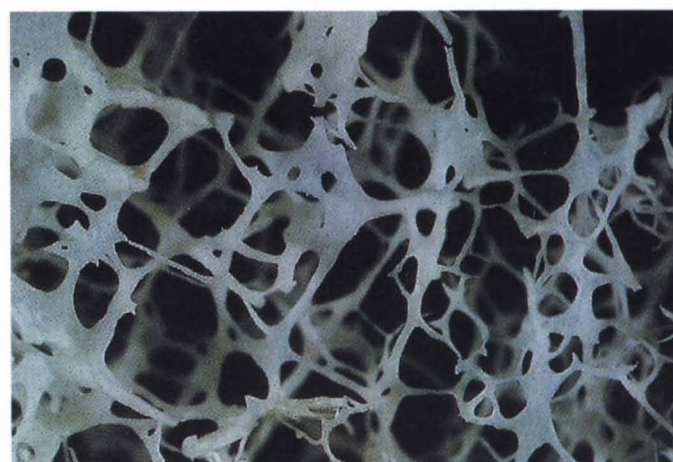
Osteoclasts and osteoblasts operate as a bone-remodeling unit. A properly functioning bone remodeling cycle is a tightly coupled physiologic process in which resorption equals formation and the net bone mass is maintained. The length of the resorption process is about one week compared to a longer formation process of about 3 months. At any point in time there are millions of remodeling sites within the body that are in different phases of the remodeling cycle or at rest.

When the cycle becomes uncoupled, the result is a net loss of bone mass. Some reasons for uncoupling are enhanced osteoclastic recruitment, impaired osteoblastic activity, and an increased number of cycles, which results in shorter time for each cycle. This favors the shorter resorption phase over the longer formation phase.

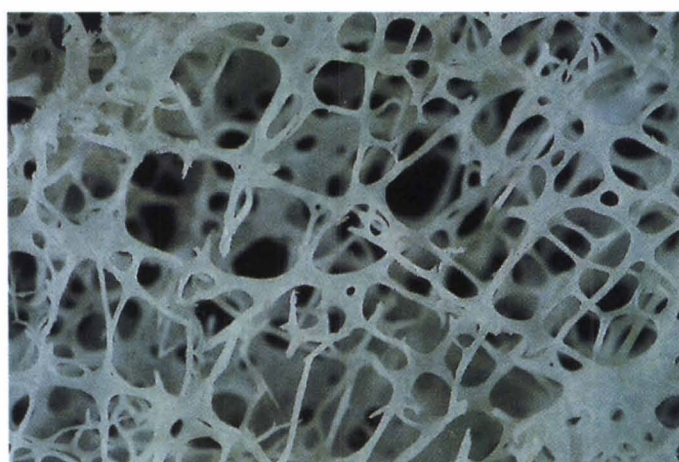
Bone mass increases in youth until *peak bone mass* is reached at about 30 to 35 years of age. This is followed by a stable period in middle age. Then comes a period of decreasing bone mass starting at about age 50 in women and somewhat later in men. The decrease in bone mass becomes pronounced in women at menopause because of the loss of bone-preserving estrogen. If the peak bone mass is low and/or the resorption rate is excessive at menopause, osteoporosis may result (Fig. 39-4).



A



C



B

**Fig. 39-4** Trabecular bone obtained from vertebrae. **A**, Normal bone. **B**, Osteoporotic bone. **C**, Severely osteoporotic bone. Note the progressive loss of trabecular continuity resulting from resorptive perforations in the severely osteoporotic subject.

(From Eriksen E: *Bone histomorphometry*, Philadelphia, 1994, Lippincott-Raven.)

## Osteoporosis<sup>1</sup>

Osteoporosis is a disease characterized by a decrease in bone mass and degradation of bone architecture to a level that bones may not support the mechanical stress and loading of normal activity. As a result, the bones are at increased risk for *fragility fractures*. It is estimated that 10 million Americans have osteoporosis with 80% (8 million) of those being women. Another 18 million Americans have *osteopenia* or low bone mass, putting them at risk of developing osteoporosis in the future. Persons with osteoporosis may experience decreased quality of life from the pain, deformity, and disability of fragility fractures (especially at the hip and spine) and increased risk of morbidity and mortality, especially from hip fractures. In the United States, annual medical costs for osteoporosis, including hospitalization for fragility fractures, is estimated at \$10 to \$15 billion.

<sup>1</sup>Appreciation is extended to Pam Johnson, R.T. (BD) for her work in the preparation of the osteoporosis section.

Many risk factors for osteoporosis have been studied and identified. The following are considered primary risk factors:

- Female sex
- Increased age
- Estrogen deficiency
- Caucasian race
- Low weight (less than 127 lbs. or 58 kg) and/or low body mass index (BMI is weight in kg divided by height in meters squared)
- Family history of osteoporosis
- History of prior fracture as an adult
- Smoking tobacco

Osteoporosis is often overlooked in older men because it is considered a woman's disease. The facts are that 2 million American men have osteoporosis and another 3 million have low bone mass. This means that 20% of Americans diagnosed with osteoporosis are men. In contrast, men suffer 33% of all hip fractures and one third of these men will not survive a year. Clearly men are at risk for the devastating effects of fragility fracture and would benefit from increased diagnosis and treatment of osteoporosis.

The exact cause of osteoporosis is not known, but it is clearly a multifactorial disorder. Major contributors are genetics, metabolic factors regulating internal calcium equilibrium, lifestyle, aging, and menopause. Peak bone mass attained in young adulthood coupled with the rate of bone loss in older age determines whether an individual's bone mass becomes low enough to be diagnosed as osteoporosis. It is estimated that genetic factors account for up to 70% of the peak bone mass attained. This is why family history is an important risk factor for osteoporosis and fracture. Calcium equilibrium is maintained by a complex mechanism involving hormones (parathyroid, calcitonin, and vitamin D) controlling key ions (calcium, magnesium, and phosphate) within target tissues (blood, intestine, and bone). Calcium and phosphate enter the blood from the intestine and are stored in bone. The process also occurs in reverse, moving calcium out of the bones for other uses within the body. Nutritional and lifestyle factors can upset the balance and cause too much calcium to move out of bone. In the course of normal aging there is a loss of estrogen at menopause which tends to increase the rate of bone turnover and thereby increase the number of remodeling cycles and shorten the length of each cycle. This allows enough time for the shorter resorption process, but cuts short the longer formation process. Various combinations of these factors can result in a net loss of bone mass and thereby increase the risk of osteoporosis and fracture.



There are two important points to note about osteoporosis. First, an older person with a normal rate of bone loss may still develop osteoporosis if their peak bone mass was low. Second, it is a common misconception that proper exercise and diet at menopause prevent bone loss associated with the decrease in estrogen. This is not true. Persons concerned about their risk of osteoporosis should consult their physician.

Osteoporosis can be classified as primary or secondary. It is important to note that a DXA scan result should not automatically lead to a diagnosis of primary osteoporosis. Secondary causes of systemic or localized disturbances in bone mass must be ruled out before a final diagnosis can be made. Proper choice of treatment should be based on type of osteoporosis and the underlying cause, if secondary osteoporosis is present. The choice of skeletal site to measure depends on the disease process, whether it has a predilection for certain types of bone, and the composition of various skeletal sites (see Table 39-1).

*Primary osteoporosis* can be *Type I* (postmenopausal) and/or *Type II* (senile or age-related). Type I osteoporosis is caused by bone resorption exceeding bone formation due to estrogen deprivation in women. Type II osteoporosis occurs in aging men and women from a decreased ability to build bone.

*Secondary osteoporosis* is osteoporosis caused by a heterogeneous group of skeletal disorders resulting in imbalance of bone turnover. Disorder categories include genetic, endocrine and metabolic, hypogonadal, connective tissue, nutritional and gastrointestinal, hematologic, malignancy, and use of certain prescription drugs. Common causes of secondary osteoporosis include *hyperparathyroidism*, gonadal insufficiency (including estrogen deficiency in women and hypogonadism in men), *osteomalacia* (rickets in children), rheumatoid arthritis, anorexia nervosa, gastrectomy, *adult sprue* (hypersensitivity to gluten (wheat protein)), multiple myeloma, and use of corticosteroids, heparin, anti-convulsants, or excessive thyroid hormone treatment.

Several prescription medications arrest bone loss and may increase bone mass. These include traditional estrogen or hormone replacement therapies and the newer bisphosphonates, selective estrogen receptor modulators (SERMs), and salmon calcitonin. Other therapies are in clinical trials and may be available in the future (Table 39-2). The availability of therapies beyond the traditional estrogens has led to the widespread use of DXA to diagnosis osteoporosis.

Laboratory tests for *biochemical markers* of bone turnover may be used in conjunction with DXA to determine the need for or the effectiveness of therapy. Problems of poor precision and individual variability have limited their use. Some markers of bone formation found in blood are alkaline phosphatase, osteocalcin, and C- and N-propeptides of type I collagen. Some markers of bone resorption excreted in urine are pyridinium cross-links of collagen, C- and N-telopeptides of collagen, galactosyl hydroxylysine, and hydroxyproline.

**TABLE 39-2**

Therapies for osteoporosis

Generic name	Some FDA approved formulations as of 2002		Primary method of action	Comments
	Treatment	Prevention		
Estrogen	Yes	No	A	Provides relief of menopausal symptoms
Bisphosphonates	Yes	Yes	A	Some formulations approved for men
Selective estrogen receptor modulators (SERM)	Yes	Yes	A	May provide some protection against breast cancer
Calcitonin	Yes	No	A	Analgesic effect after acute fracture
Fluoride	No	No	F	
Growth hormone	No	No	F	
Parathyroid hormone (PTH)	Yes	No	F	Approved for men and women at high risk for fracture
Statins	No	No	F	
Anabolic steroids	No	No	F	

A. Anti-resorptive; F, formation.

## FRACTURES AND FALLS

Fractures occur when bones encounter an outside force that exceeds their strength. Fragility fractures occur with minimal trauma from a standing height or less. A small percentage of fragility fractures are spontaneous, meaning that they occur with no apparent force being applied. The most common sites for fractures associated with osteoporosis are the hip, spinal vertebrae, wrist (Colles fracture), ribs, and proximal humerus, but other bones can be affected. Current estimates of fracture in the United States are that approximately 1.5 million osteoporotic fractures occur each year; these include 700,000 vertebral (only one third are clinically diagnosed), 300,000 hip, 250,000 wrist and 300,000 other fractures. One in two women and one in eight men over age 50 will have an osteoporotic fracture in their lifetime.

Risk factors for fracture include low bone mass, personal history of fracture as an adult, history of fracture in first-degree relative, current cigarette smoking, and low body weight (less than 127 lbs. or 58 kg).

Hip fractures account for 20% of osteoporotic fractures and are the most devastating both for the patient and in terms of health costs. Some important points about hip fracture include the following:

- The overall 1 year mortality rate following hip fracture is 1 in 5<sup>1</sup>
- Two to 3 times as many women as men suffer hip fractures, but the 1 year mortality rate for men is twice as high
- Two-thirds of hip fracture patients never regain their preoperative activity status. One-fourth require long-term care.
- A woman's risk of hip fracture is equal to her combined risk of breast, uterine, and ovarian cancer
- Protective undergarments with side padding, called hip pads, have proven effective in preventing hip fracture from a fall in the elderly. Resistance to wearing the garment is the only limitation.

<sup>1</sup>National Institutes of Health Consensus Development Panel on Osteoporosis Prevention, Diagnosis, and Therapy: Osteoporosis Prevention, Diagnosis, and Therapy, *JAMA* 285 (6): 785, 2001.

Vertebral fractures are the most common osteoporotic fracture but only approximately one third are clinically diagnosed. The effects of vertebral fractures have traditionally been underestimated, but are beginning to be recognized and quantified. These fractures cause pain, disfigurement, dysfunction, decrease the quality of life, and recent studies link them to an increased risk of mortality. Vertebroplasty and kyphoplasty are minimally invasive procedures for managing acute painful vertebral fractures that have not responded to conventional treatment. They involve injecting bone cement into the fractured vertebra. The presence of even one osteoporotic vertebral fracture significantly increases the risk of future vertebral fractures and progressive curvature of the spine.

Most osteoporotic fractures are caused by falls. Therefore identifying elderly persons at increased risk for falls and instituting fall prevention strategies are important goals. Some risk factors for falling are use of some medications including sedatives, sleep aids, and antidepressants; impaired muscle strength, range of motion, balance, and gait; impaired psychological functioning including dementia and depression; and environmental hazards including lighting, rugs, furniture, bathroom, and stairs. Some fall prevention strategies are physical therapy including balance, gait, and strengthening exercises; address psychological issues; review medication regimens and counsel patient on correct dosing; and inspect home for hazards and install safety measures.

## UNIVERSAL RECOMMENDATIONS

The following interventions have multiple health benefits and are sufficiently cost-effective to be recommended to the general public to maximize and preserve bone mass:

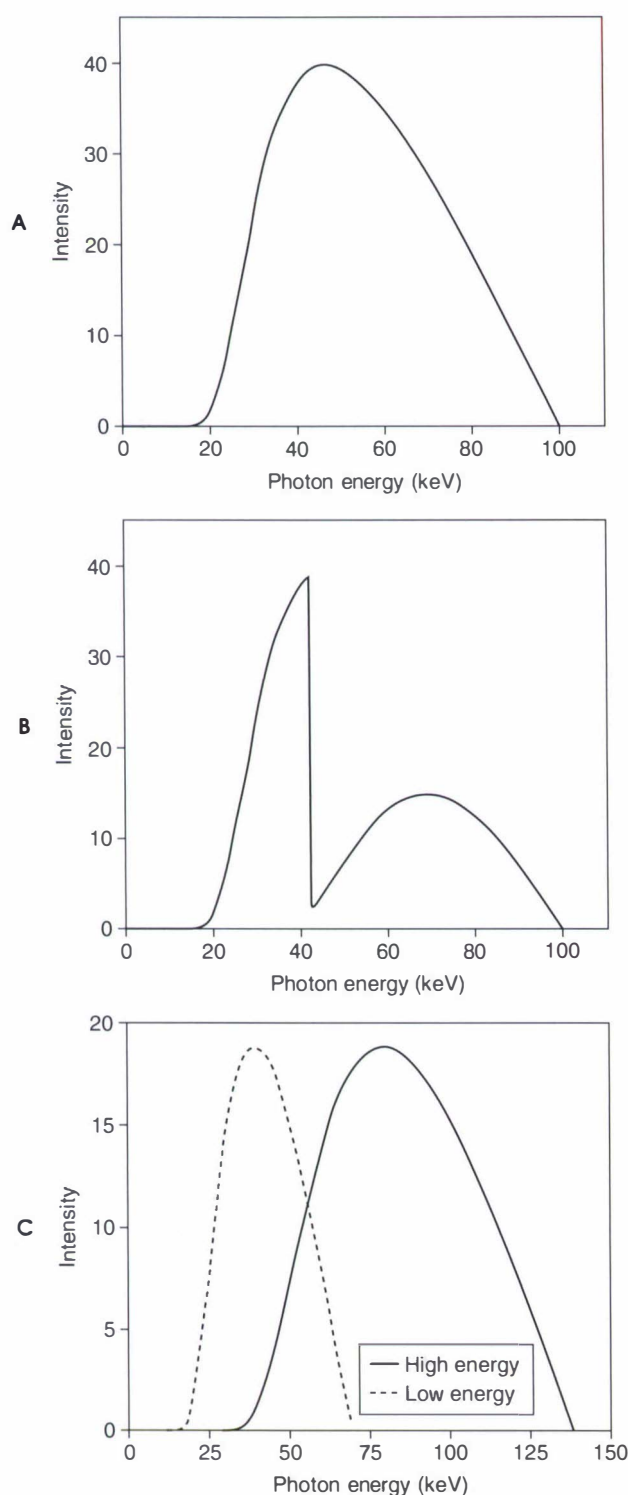
- Lifelong adequate intake of calcium and vitamin D
- Regular weight-bearing and muscle-strengthening exercise to reduce the risk of falls and fractures
- Avoid tobacco and use alcohol moderately

Many Americans fail to meet currently recommended guidelines for optimal calcium intake. The National Institute of Health Consensus Conference recommends the following calcium intake: 1000 mg/day for women age 25 to 50, postmenopausal women on estrogen therapy, and men ages 25 to 65; and 1500 mg/day for postmenopausal women not on estrogen therapy and men over age 65. Dietary calcium is the best source, including yogurt, milk, some cheeses, tofu, salmon, spinach, and broccoli. Dietary shortfall should be met with calcium supplements with the USP designation that supply the appropriate amount of elemental calcium. Be sure to check the number of pills to meet the serving size and whether or not to take with food.

Adequate intake of Vitamin D (at least 400 IU per day) is essential for calcium absorption and bone health. Some calcium supplements and most multivitamins contain Vitamin D. Dietary sources are Vitamin D fortified milk and cereals, egg yolks, salt water fish, and liver.

Weight-bearing exercise occurs when bones and muscles work against gravity as the feet and legs bear the body's weight. Some examples are weight lifting to improve muscle mass and bone strength, low-impact aerobics, walking or jogging, tennis, dancing, stair climbing, gardening, and household chores.





**Fig. 39-5** Energy spectra (keV) for x-ray sources used in bone densitometry instruments. **A**, Continuous spectrum from an X-ray tube. **B**, Continuous X-ray spectrum modified by a K-edge filter. **C**, High- and low-energy spectra from a KV switching system.

(Courtesy Blake G. Wahner H. Fogelman I: *The evaluation of osteoporosis: dual energy x-ray absorptiometry and ultrasound in clinical practice*, London, 1998, Martin Dunitz.)

## Physical and Mathematical Principles of Dual Energy X-ray Absorptiometry

The measurement of bone density requires separation of the x-ray attenuating effects of soft tissue and bone. The mass attenuation coefficients of soft tissue and bone differ and also depend on the energy of the x-ray photons. The use of two different photon energies (dual energy x-ray) optimizes the differentiation of soft tissue and bone. Lunar and Norland use a different method of producing the two energies than Hologic.

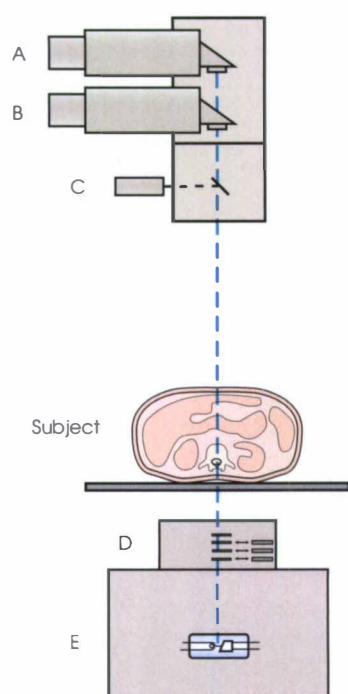
Lunar and Norland use a rare-earth filtered x-ray source. The primary x-ray beam is passed through selected rare-earth filters to produce a spectrum with peaks near 40 and 70 kiloelectron volts (keV), as compared to the usual continuous spectrum with one peak near 50 keV (Fig. 39-5, A and B). Sophisticated pulse counting detectors are used to separate and measure the low and high energy photons (Fig. 39-6). Calibration must be performed externally by scanning a calibration phantom on a regular basis.

The Hologic scanners use an energy-switching system that synchronously switches the x-ray potential between 100 and 140 kVp. This produces a primary beam with two photon energies with peaks near 40 and 80 keV (see Fig. 39-5, C). The energy-switching system continuously calibrates the beam by passing it through a calibration wheel (Fig. 39-7) or drum containing three sectors for an open air gap, a soft tissue equivalent, and a bone equivalent. Each sector is divided so that it can differentiate and measure the low and high energy photons. This permits the use of a relatively simple current-integrating detector that does not have to separate the photons.

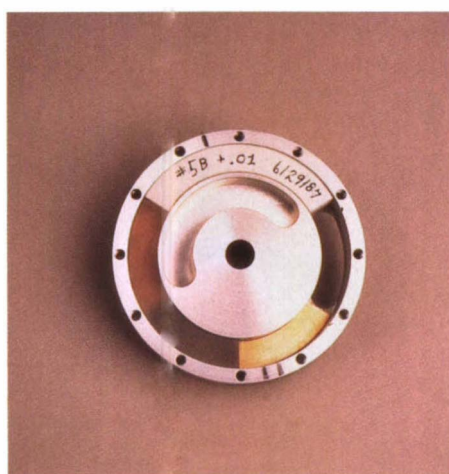
Common physics problems of DXA are:

- Beam hardening in energy switching systems. With increasing body thickness, a higher proportion of low energy photons are absorbed within the body, shifting the spectral distribution towards high energy photons. This is solved by continuous calibration with a rotating filter wheel or drum.
- Detector pileup in K-edge filtration systems. A detector can only process one photon at a time and assign it to the high or low energy channel. An incoming photon may be missed if the preceding photon has not yet been processed. This is solved by adequate detector speed and using a lower tube current on scans of thin body parts or air.
- Cross-over in K-edge filtration systems. Some high energy photons lose energy passing through the body and are counted as low energy photons by the detector. This is solved by subtracting a fraction of the high energy counts from the low energy channel, depending on body thickness.

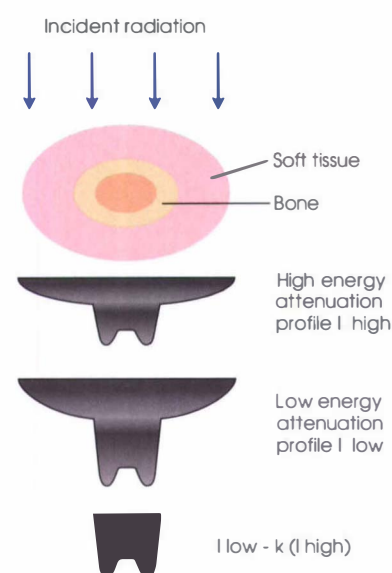
The low and high energy x-rays are attenuated differently within each patient. This produces a unique attenuation pattern at the detector which is transmitted electronically to the scanner software. Mathematical computations are then performed that subtract the soft tissue signals, thereby producing a profile of the bone (Fig. 39-8). Proprietary bone edge detection algorithms are next applied, and a two-dimensional area is calculated. The average BMD is calculated for all unit areas, and finally the *bone mineral content (BMC)* is calculated as  $BMC = BMD \times \text{area}$ . Thus the three bone densitometry parameters reported on the DXA printouts are area in centimeters squared ( $\text{cm}^2$ ), BMC in grams (g), and BMD in  $\text{g}/\text{cm}^2$ . BMD is the most widely used parameter because it reduces the effect of body size.



**Fig. 39-6** Schematic drawing of a Norland model XR-36 illustrating the principle of operation of a rare-earth filtered system. A, High-energy detector. B, Low-energy detector. C, Laser indicator. D, Samarium filter module (one fixed, three selectable). E, Ultra-stable 100 kV x-ray source.



**Fig. 39-7** Calibration wheel used as internal reference standard in Hologic energy-switching instruments. The different segments represent a bone standard, a soft tissue standard, and an empty segment for air value.



**Fig. 39-8** Soft tissue compensation using DXA. By obtaining data at two energies, the soft tissue attenuation can be mathematically eliminated. The remaining attenuation is due to the amount of bone present.

(Courtesy Faulkner KG: *DXA basic science, radiation use and safety, quality assurance*, unpublished certification report, 1996, Personal communication, Madison, WI.)

BMD can be calculated if BMC and area are known by the equation  $BMD = BMC/area$ . This equation can be used to determine if a change in BMD is due to a change in BMC or area or both. A decrease in BMC results in a decrease in BMD while conversely a decrease in area results in an increase in BMD. If BMC and area move proportionally in the same direction, BMD remains unchanged. Generally a change in a patient's BMD over time should be from a change in BMC, not area. A change in area could be from the technologist not reproducing the baseline positioning or from a change in the software's bone edge detection. Changes in area over time should be investigated and corrected, if possible.

BMD is based on a two-dimensional area, not a three-dimensional volume, making DXA a *projectional*, or *areal*, technique. Techniques to estimate *volumetric density* from DXA scans have been developed but have not been shown to have any improved diagnostic sensitivity over traditional areal density. Fig. 39-9 shows the AP spine areal BMD and the lateral spine areal and estimated volumetric BMDs.

BMD values from scanners made by different manufacturers cannot be directly compared. However, mathematical formulas have been developed for converting BMD from any manufacturer to *standardized BMD (sBMD)* values that can be compared.<sup>1,2</sup> Standardized BMD values are best used for large populations, such as standardizing a reference population database. They must be used with caution for individuals because the sBMD from one manufacturer can vary by 3% to 6% from the sBMD of either of the other manufacturers. For this reason, it is not widely recommended to use sBMD to compare an individual's scans done on different manufacturers' scanners.

<sup>1</sup>Genant HK: Development of formulas for standardized DXA measurements, *J Bone Miner Res* 9:997, 1995.

<sup>2</sup>Genant HK et al: Universal standardization for dual x-ray absorptiometry: patient and phantom cross-calibration results, *J Bone Miner Res* 9:1503, 1994.

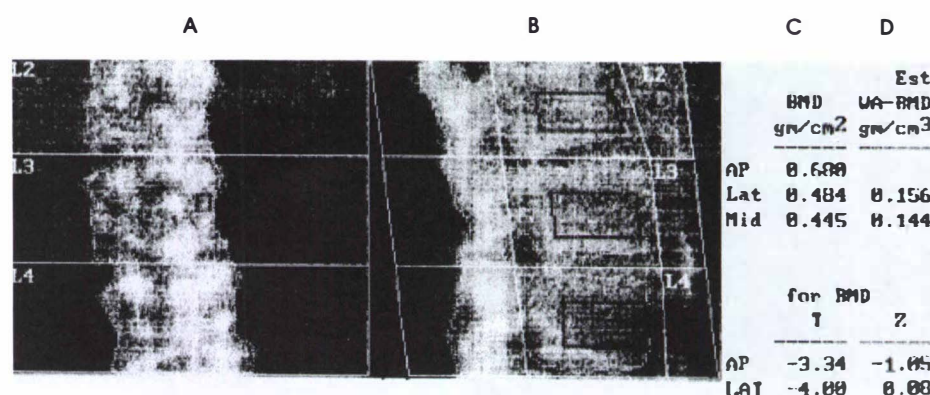


Fig. 39-9 Partial printout for Hologic AP spine scans (A) and supine lateral spine scans (B), showing scan images and BMD, T-scores, and Z-scores for areal densities (C) and estimated volumetric (D) densities.



## Pencil-Beam Versus Array-Beam

The original DXA scanners employed a pencil-beam system. With this system a circular pinhole x-ray collimator produces a narrow (or pencil-beam) stream of x-ray photons that is received by a single detector. The pencil-beam of x-ray moves in a serpentine (also called rectilinear or raster) fashion across or along the length of the body (Fig. 39-10). This system has good resolution and reproducibility, but the early scanners had relatively long scan times of 5 to 7 minutes. Furthermore, the system is not compatible with the newer C-arm design, which allows supine lateral lumbar spine scans. It should be noted that pencil-beam systems are very stable and are still in widespread use, with modern systems incorporating enhancements to improve image quality and achieve shorter scan times.

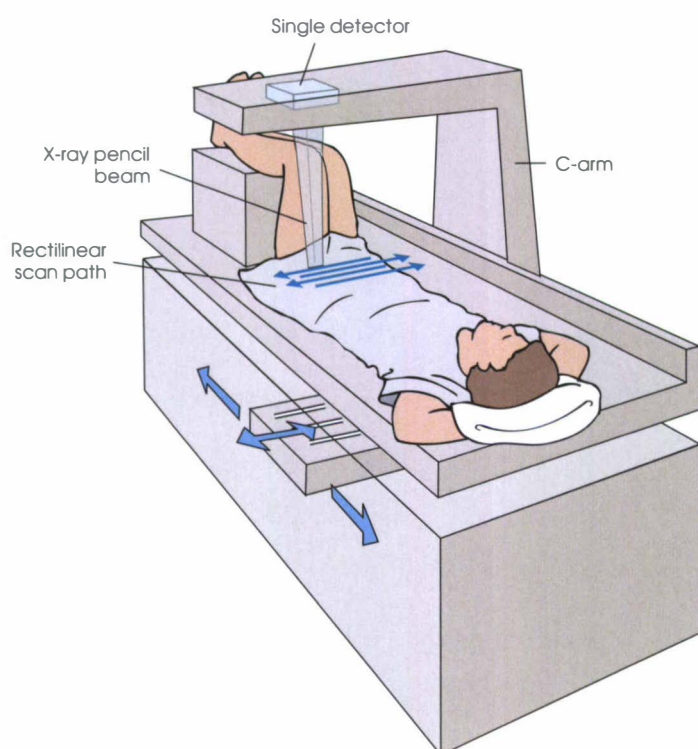
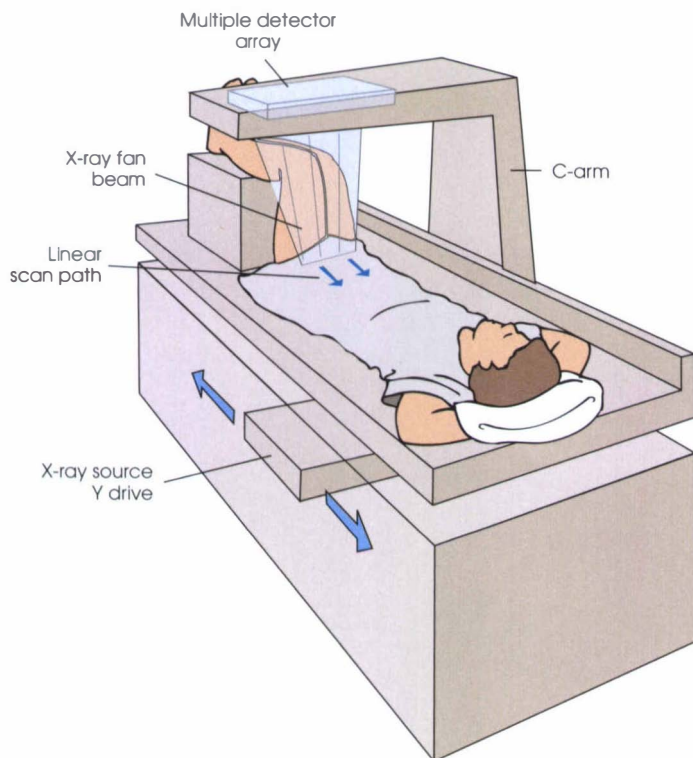
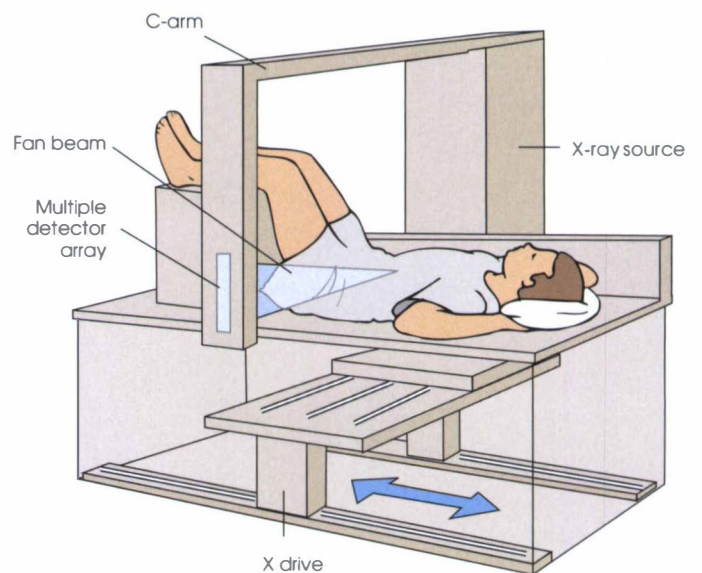


Fig. 39-10 DXA system using a pencil-beam single detector.

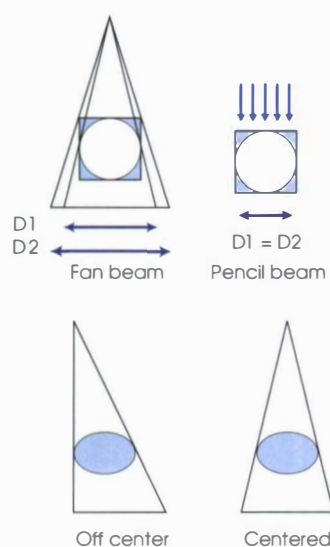


**Fig. 39-11** DXA system using an array-beam multiple detector.



**Fig. 39-12** DXA system using a movable C-arm and array-beam multiple detector to perform a lateral supine lumbar spine scan.

The array-beam (also called fan-beam) system has a narrow “slit” x-ray collimator and a multielement detector (Fig. 39-11). The scanning motion is reduced to only one direction, which greatly reduces scan time and permits supine lateral lumbar spine scans to be performed (Fig. 39-12). The array-beam system introduces geometric magnification and a slight geometric distortion at the outer edges. Consequently, careful centering of the object of interest is necessary to avoid parallax (Fig. 39-13). The software takes into account the known degree of magnification and produces an estimated BMC and estimated area.



**Fig. 39-13** Potential array-beam errors, including magnification (*top*) and parallax (*bottom*). Both area and BMC are influenced by magnification to the same degree, such that the BMD is not significantly affected. Parallax errors can cause changes in BMD by altering the beam path through the object being measured.

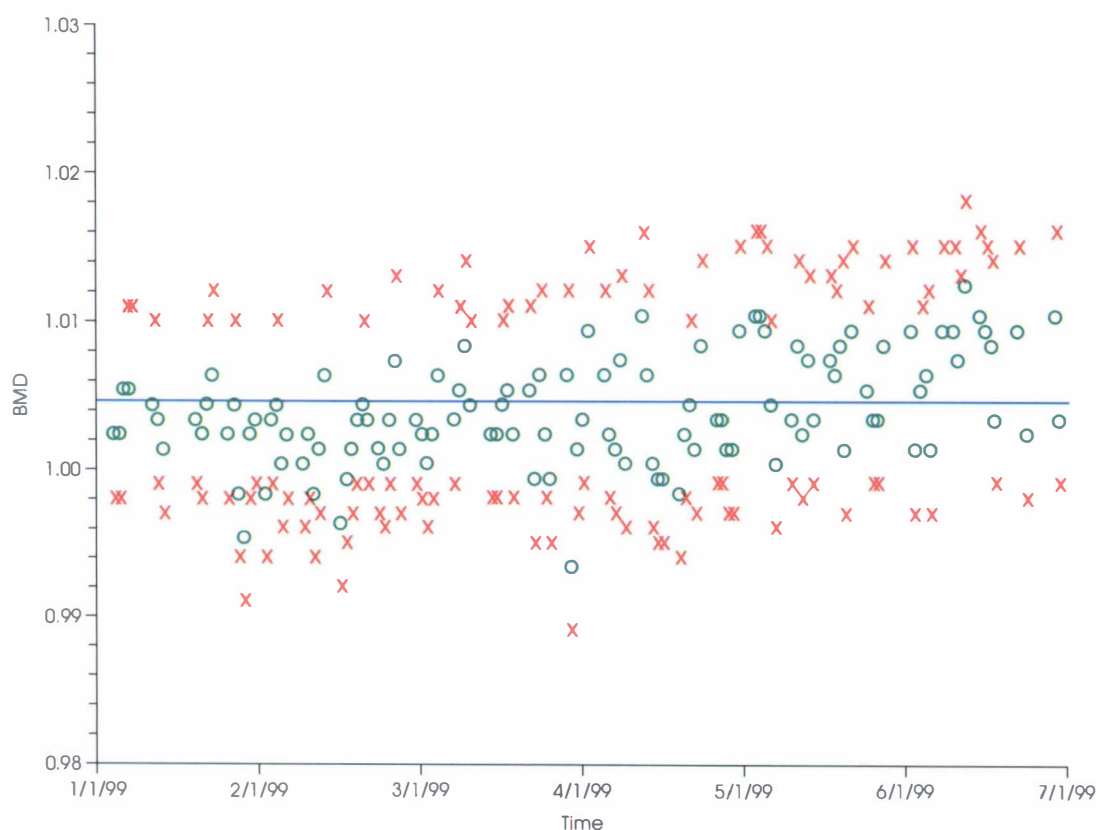
(Courtesy Faulkner KG: *DXA basic science, radiation use and safety, quality assurance*, unpublished certification report, 1996, Personal communication, Madison, W.I.)



## ACCURACY AND PRECISION

Three statistics are particularly important in bone densitometry: *mean*, *standard deviation (SD)*, and *percent coefficient of variation (%CV)*.

1. The mean is commonly called the average. It is the sum of the data values divided by the number of values.
2. The SD is a measure of variability that measures the spread of the data values around their mean. It takes into account the average distance of the data values from the mean. The smaller the average distance or the spread, the smaller the SD. In bone densitometry, a smaller SD is better. Fig. 39-14 plots two sets of phantom BMD data measured over six months. The means are the same ( $1.005 \text{ g/cm}^2$ ) but the red dataset has a SD that is twice as large as that of the green dataset ( $0.008 \text{ g/cm}^2$  versus  $0.004 \text{ g/cm}^2$ ). It is better to have phantom BMD data that look like the green dataset.



**Fig. 39-14** Two datasets of longitudinal phantom BMD (blue line is the mean). Green dataset has mean =  $1.005 \text{ g/cm}^2$ , SD =  $0.004 \text{ g/cm}^2$ , and %CV = 0.35. Red dataset has mean =  $1.005 \text{ g/cm}^2$ , SD =  $0.008 \text{ g/cm}^2$ , and %CV = 0.81.

3. The %CV is a statistic that allows the comparison of variability between different data sets, whether or not they have the same mean. A smaller %CV means less variability and is preferred in bone densitometry. The %CV is calculated using the following equation:

$$\%CV = (SD/Mean) \times 100$$

In Fig. 39-14 the green dataset has a %CV of 0.35 and the red dataset has a %CV of 0.81. This is the %CV that must be checked on a Hologic spine phantom plot (Fig. 39-15). The Red data would not pass the criteria that the %CV should be less than or equal to 0.6. The %CV is also used to express precision.

Bone densitometry differs from diagnostic radiology in that good image quality, which can tolerate variability in technique, is not the ultimate goal. Instead, the goal is accurate and precise quantitative measurement by the scanner software, which requires stable equipment and careful, consistent work from the technologist. Therefore two important performance measures in bone densitometry are *accuracy* and *precision*. Accuracy relates to the ability of the system to measure the true value of an object. Precision relates to the ability of the system to reproduce the same (but not necessarily accurate) results in repeat measurements of the same object. A target may be used to illustrate this point. In Fig. 39-16, A, the archer is precise but not accurate. In Fig. 39-16, B, the archer is accurate but not precise. Finally, in Fig. 39-16, C, the archer is both precise and accurate.

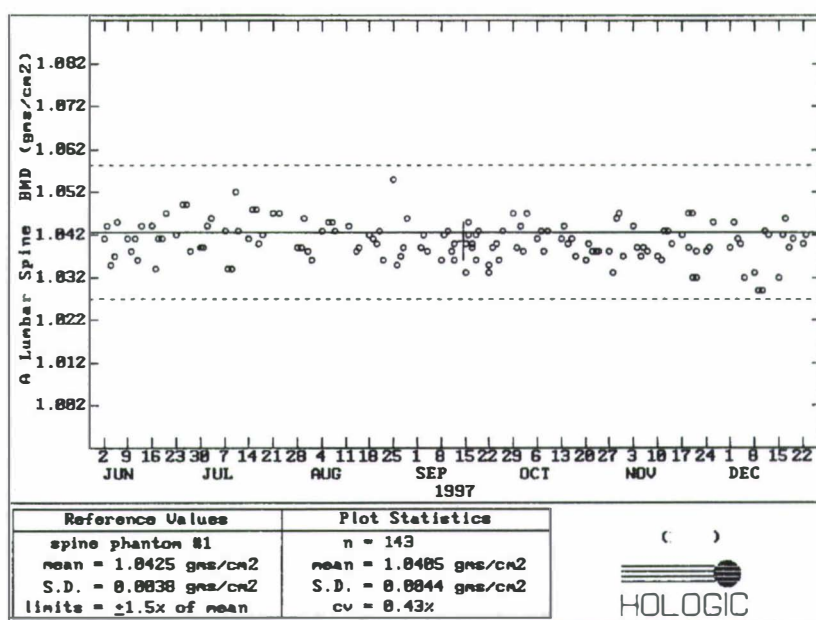


Fig. 39-15 Hologic spine phantom quality control plot. All plotted BMD points are within the control limits (dotted lines), which indicate 1.5% of the mean. The coefficient of variation (CV) (under Plot Statistics) is within acceptable limits at 0.43% (arrow).

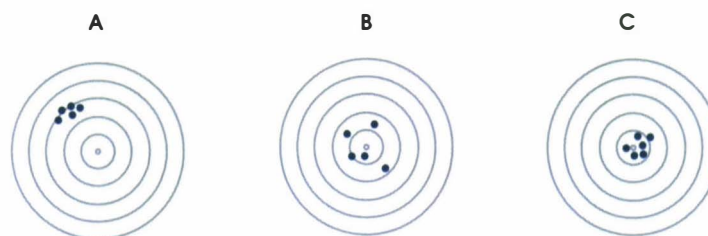


Fig. 39-16 Illustration of accuracy versus precision, assuming an archer is shooting for the center of the target. A, Precise but not accurate. B, Accurate but not precise. C, Accurate and precise.

In bone densitometry practice, accuracy is most important at baseline when the original diagnosis of osteoporosis is made. Accuracy is determined primarily by the calibration of the scanner, which is set and maintained by the manufacturer. Preventive maintenance once or twice a year is recommended. Precision is followed closely because it is relatively easy to determine and is the most important performance measure in following a patient's BMD over time. Precision can be measured *in vitro* (in an inanimate object, e.g., phantom) or *in vivo* (in a live body). It is commonly expressed as %CV, and a smaller value indicates better precision.

*In vitro* precision is the cornerstone of the quality control systems built into the scanners to detect drifts or shifts (variations) in calibration. Each manufacturer provides a unique phantom for this purpose, but a rule of thumb is that a Hologic *anthropomorphic* spine phantom measured at least 3 days a week over several months on any of the three manufacturers' scanners should have a %CV no greater than 0.5 to 0.7. The Hologic quality control plot (see Fig. 39-15) provides the %CV for the plotted BMD results.

*In vivo* precision has two main aspects in bone densitometry:

1. The variability within a patient that makes it easy or difficult to obtain similar BMD results from several scans on the same patient, on the same day, with repositioning between scans. (Patients with abnormal anatomy, very low bone mass, or thick or thin bodies are known to have worse precision.)
2. The variability related to the skill of the technologist and how attentive they are to obtaining the best possible baseline scan and then reproducing the positioning, scanning parameters, and placement of ROI on all *follow-up scans*.

It is important that each DXA lab knows its *in vivo* precision. This precision is used to determine the magnitude of change in BMD that must occur over a period of time to be certain that the change is due to a change in the patient's BMD, not to the precision error of the technologist and scanner. Calculating *in vivo* precision involves performing multiple scans on a number of patients and computing some statistical parameters.<sup>1,2</sup> Although this process is time-consuming, it is worth the effort involved. *In vitro* precision can never be substituted into a formula that requires *in vivo* precision.

The primary factors affecting precision include the following:

- Reproduction of positioning, acquisition parameters (e.g., mode, speed, current), and ROI placement
- Anatomic variations and pathology and their degeneration over time
- Body habitus (e.g., excessive thickness or thinness)
- Large weight changes over time
- Geometric factors on array scanners
- Stability of scanner calibration and bone edge detection

<sup>1</sup>Bonnick SL: *Bone densitometry in clinical practice: application and interpretation*, Totowa, NJ, 1998, Human Press.

<sup>2</sup>Glüer CC et al: Accurate assessment of precision errors: how to measure the reproducibility of bone densitometry techniques, *Osteoporos Int* 5:262, 1995.



## Z-SCORES AND T-SCORES

A BMD measurement from a patient is most useful when it can be compared statistically to an appropriate sex-matched *reference population*. The three DXA manufacturers have separately collected reference population databases. These reference databases vary because different populations, entrance criteria, and statistical methods were used. To correct this problem, the third National Health and Nutrition Examination Survey (NHANES III) DXA total hip database was adapted to provide a standardized hip reference database for all manufacturers. It is widely used today. All reference databases are separated by gender and provide the BMD mean and SD at each age.

In order to compare a patient's BMD with the reference population BMD, two standardized scores have been developed called the *Z-score* and *T-score* (see Fig. 39-9, C). In older adults the Z-score will be greater than the T-score.

The Z-score indicates the number of SDs the patient's BMD is from the average BMD for the patient's respective age and sex group. Z-score is used to determine if the measured BMD is reasonable and if evaluation for secondary osteoporosis is warranted. It is calculated using the following:

$$\text{Z-score} = (\text{Measured BMD} - \text{Age-matched mean BMD}) / \text{Age-matched SD}$$

The T-score indicates the number of SDs the patient's BMD is from the average BMD of young, normal, sex-matched individuals with peak bone mass. T-score is used to assess fracture risk, diagnose osteoporosis and *osteopenia*, and determine if therapy is recommended. It is calculated using the following:

$$\text{T-score} = (\text{Measured BMD} - \text{Young adult mean BMD}) / \text{Young adult SD}$$

The Z-score and/or T-score may also be adjusted for ethnicity and/or weight. It is incorrect to assume that because ethnicity and weight have been entered into the scan biographical information that the standardized scores have been adjusted. Some manufacturers allow an ethnicity to be entered for which there is no reference database; these patients are compared to Caucasian. Some manufacturers adjust for weight and ethnicity on the Z-score but not the T-score. To determine what adjustments have been made, first carefully check the information on the scan print-out, including footnotes. If a question remains, call the manufacturer's Customer Service line and ask.

Bone mass is normally distributed (i.e., has a bell-shaped curve) in the population, and no one exact cut point exists below which a person has osteoporosis. However, with the widespread availability of DXA and T-scores, there was pressure to declare such a cut point. In 1994 the World Health Organization (WHO) recommended that the classifications presented in Table 39-3 be used in DXA studies of post-menopausal Caucasian women.

*Discordance* refers to the issue of different T-scores occurring at anatomical sites within a patient, within populations, and between modalities. It makes the diagnosis of osteoporosis more complicated than simply applying a T-score criteria, and the problems are being researched to find more standardized diagnostic criteria. For example, a patient may be found to have a low T-score at the hip but not at the spine and a QCT scan of the spine is likely to produce a lower T-score than a DXA scan of the spine in the same patient.

The WHO classifications have become widely used in clinical practice. However, applying the T-score criteria designed for DXA to other modalities (e.g., QUS, QCT) has proved to be problematic. The best practice is to apply the T-score criteria only to DXA until ongoing research provides acceptable criteria for other modalities. It is very important to note that the T-score is one important risk factor for osteoporosis, but the patient's medical history, life style, medications, and other risk factors must also be considered in a complete clinical evaluation. Physicians who interpret bone density scans need to be educated in the complexities of the task.

Large epidemiologic studies have investigated the clinical value of BMD in elderly women and have yielded information on the relationship of BMD and T-scores to fracture risk. A gradient of risk has been observed between BMD and fracture incidence, with lower BMD or T-score conferring increased risk of fracture. For each 1 SD decrease in T-score, the risk for fracture increases 1.5 to 2.5-fold. For example, a woman with a T-score of  $-2$  has roughly twice the risk of fracture compared with a woman with a T-score of  $-1$ , all other factors being equal. This information helps clinicians explain the meaning of a bone density test to patients. Patients can then make informed decisions about the level of fracture risk they are willing to accept and whether to begin or continue therapy.

**TABLE 39-3**

World Health Organization classifications of bone density by T-score

Classification	Criteria
Normal	BMD or BMC T-score of $\geq -1$
Low bone mass (osteopenia)	BMD or BMC T-score between $-1$ and $-2.5$
Osteoporosis	BMD or BMC T-score of $< -2.5$
Severe osteoporosis	BMD or BMC T-score of $< -2.5$ and one or more fragility fractures

BMD, Bone mineral density; BMC, bone mineral content; T-score, the number of standard deviations a BMD is from the average BMD of a young, normal, sex-matched individual with peak bone mass.

Data from Kanis JA: World Health Organization (WHO) Study Group: assessment of fracture risk and its application to screening for post menopausal osteoporosis: a synopsis of the WHO report, *Osteoporos Int* 4:368, 1994.

# Dual Energy X-ray Absorptiometry Scanning

## RADIATION PROTECTION

Radiologic technologists receive extensive instruction in radiation physics, biology, and protection during their professional education. Practicing proper radiation protection and achieving the goal of *ALARA* (*As Low As Reasonably Achievable*) is relatively simple for DXA. The effective radiation dose in *sieverts* (*Sv*) for DXA scans is very low compared with conventional radiography doses and similar to natural background radiation (Table 39-4). If the positioning or acquisition parameters of a scan are questionable, the scan should be repeated because the risk from the additional radiation dose is negligible compared to the risk of an incorrect medical diagnosis.

Time, distance, and shielding relate to DXA in the following ways:

1. The manufacturer sets the time for the scan. The slowest scan time should be used on large patients and the fastest scan time on thin patients to get the best possible accuracy and precision. For technologists, those who scan most of the day, several days a week should consider increasing their distance from the scanner or using a mobile radiation shield.
2. The manufacturer sets the distance from the x-ray tube to the patient. For technologists, distance is the best form of protection. The computer console should be at least 3 feet (1 meter) from the scanner for pencil-beam scanners and up to 9 feet (3 meters) from heavily used array-beam scanners (array-beam produces higher dose than pencil-beam). If these distances can not be accommodated, a mobile radiation shield can be used.

Shielding is built into the scanner via collimation. It is not recommended to use additional lead shielding on DXA patients. Technologists may further protect themselves with a mobile radiation shield if time and distance are concerns.

Other important radiation safety points include the following:

- The technologist should wear an individual dosimetry device (film badge, thermoluminescent dosimeter [TLD], or optically stimulated luminescence [OSL] device) at the collar on the side adjacent to the scanner. Another monitor can be placed outside the scan room. A staff member should be charged with understanding and monitoring the dosimetry records and performing any necessary follow-up. A radiation warning sign should be posted and highly visible.
- The technologist should remain in the room during the scan and monitor the acquisition image, allowing the scan to be aborted as soon as the need for repositioning and rescanning is obvious.

TABLE 39-4

Bone densitometry radiation doses compared to other commonly acquired doses

Type of radiation exposure	Effective dose (mSv)
Daily natural background radiation	5-8
Round-trip air flight across the United States	60
Lateral lumbar spine radiograph	700
PA chest radiograph	50
QCT with localizer scan (from scanner offering low kV and mAs; may be up to 10 times higher for other scanners)	60
DXA scan (range allows for different anatomic sites; Lunar EXPERT-XL may be higher)	1-5
SXA scan	≤1
Quantitative ultrasound	0

PA, Posteroanterior; QCT, quantitative computed tomography; kVp, kilovolt (peak); mAs, milliamperere-seconds; DXA, dual energy x-ray absorptiometry; SXA, single energy x-ray absorptiometry.

Data from Kalender WA: Effective dose values in bone mineral measurements by photon absorptiometry and computed tomography. *Osteoporos Int* 2:82, 1992.

- The technologist should have adequate instruction and experience to minimize repositioning and repeated scans. For example, it is important to know how to prepare the patient to eliminate artifacts. However, any questionable scan should be repeated. Some labs routinely repeat serial scans that indicate a significant bone loss to verify the bone values. This will not harm the patient resulting from the very low radiation dose and will add credence to a diagnosis of bone loss.
- The technologists should follow proper procedures to avoid scanning a pregnant patient and place documentation in the permanent record. If a woman of child-bearing age will not sign that she is not pregnant, the 10 Day Rule allows scanning during the first 10 days after the first day of her last menstrual period.
- The technologist who is using a Lunar EXPERT-XL scanner must remember that this scanner employs higher levels of radiation and produces higher levels of scatter. Proper radiation protection procedures should be obtained from the manufacturer of this scanner.
- Patients should be screened at scheduling for problems that require postponement of scanning, such as pregnancy and recent barium or nuclear medicine examinations.

The most effective radiation safety practice is a knowledgeable, well educated, and conscientious DXA technologist. It is essential for DXA technologists to receive manufacturer's instruction for the specific model of scanner. This might consist of review of videotapes or CDs, and/or a one or two day session with a field applications specialist and review of performed scans. Once experience is obtained, a technologist can be certified by the International Society for Clinical Densitometry (ISCD) and/or test for a certificate of added qualifications by the American Registry of Radiologic Technologists (ARRT). Technologists should obtain continuing education in bone densitometry to stay abreast of changes and innovations.



## PATIENT CARE AND EDUCATION<sup>1</sup>

Typical DXA patients are ambulatory outpatients, however many are frail and at increased risk for fragility fractures. Patient care and safety requires attention to the following points of courtesy and common sense:

- All areas of the lab, including front entrance, waiting room, and scan room, should be monitored daily and modified for patient safety. Check the location of floor-level cables in the scan room.
- The technologist should maintain professionalism at all times by introducing self and other staff to the patient and explaining what is being done and why. It is important to listen to any concerns the patient may have about the procedure and to be ready to answer questions about radiation exposure, the length of the examination, or the reporting system used by the facility.

<sup>1</sup>Appreciation is extended to JoAnn Caudill, R.T. (BD) for her work in the preparation of the patient care and education section.

- The technologist needs to consider certain aspects of patients' clothing. Some DXA laboratories have all patients undress and put on gowns to prevent external artifacts. However, it is possible to scan a patient who is wearing loose cotton clothing with no buttons, snaps, or zippers (i.e., "sweats"); in this situation, the brassiere must be undone, and all hooks and underwires must be removed from the scan field. If shoes are removed, a long-handled shoehorn would be a practical aid.
- The technologist should provide a simple explanation of the expected action of the scan-arm, the proximity of the scan-arm to the patient's face and head, the noise of the motor, and the length of time for the scan. This information may reduce the patient's anxiety.
- Although the scan tables are not more than 3 feet (about 1 m) in height, a steady footstool with a long handle is recommended. All patients should be assisted on and off the table.
- At the end of the scan, the technologist should be sure the scan-arm has returned to the home position and have the patient sit upright for several seconds to regain stability before descending from the scanner.

In some institutions, it is the responsibility of the DXA technologist to provide education to the patient and the family. Topics may include osteoporosis prevention, proper nutrition, calcium supplementation, weight-bearing exercise, and creating a hazard-free living environment. Many technologists give community educational programs, staff in-service seminars, and participate in health fairs.

## PATIENT HISTORY<sup>1</sup>

Each bone density laboratory should develop a patient questionnaire customized for the types of patients referred and the needs of the referring and reporting physicians. The questionnaire should be directed at obtaining information in four basic categories:

1. Scanning information. Before scanning is performed, identify any information that could postpone or cancel the scan. Sample questions include the following:
  - Could you be pregnant?
  - Is it impossible for you to lie flat on your back for several minutes?
  - Have you had a nuclear medicine, barium, or contrast x-ray examination performed in the last week?
  - Have you had any previous fractures and/or surgeries in the hip, spine, abdomen, or forearm areas?
  - Do you have any other medical conditions affecting the bones, such as osteoporosis, curvature of the spine, or arthritis?
2. Patient information. This includes identifying information, referring physician, current height and weight, and medical history, including medications.
3. Insurance information. Because DXA scans are not universally covered by insurance, it is important to obtain information on the insurance carrier, the need for prior approval, and the information needed for insurance coding.

<sup>1</sup>Appreciation is extended to Peg Schmeer, CDT, and Randie Barnett, R.T. (BD), for their work in the preparation of the patient history section.

In 1998 Congress passed the Bone Mass Measurement Act (BMMA) dealing with reimbursement for Medicare patients. Both central and peripheral technologies are covered. Screening is not covered by Medicare, so a qualified individual must meet at least one of the following requirements:

- Estrogen deficient woman at clinical risk of osteoporosis
  - Person with hyperparathyroidism
  - Person receiving long term glucocorticoid (steroid) therapy
  - Person with vertebral abnormalities by radiograph
  - Person being monitored for FDA-approved osteoporosis therapy
4. Reporting information. The type and scope of the report that will be provided determines how much information is needed about the patient's risk factors for, and history of, low bone mass, fragility fractures, and bone diseases.

### REPORTING, CONFIDENTIALITY, RECORD KEEPING, AND SCAN STORAGE

Once the scan has been completed, the following guidelines should be observed:

- The technologist should end the examination by telling the patient when the scan results will be available to the referring physician. If a patient asks for immediate results, the technologist should explain that it is the physician's responsibility to interpret and explain DXA results.
- The technologist should remember that DXA scan results are confidential medical records and should be handled according to the institution's rules for such records. Results should not be discussed with other staff or patients, and printed results, whether on hard copy or a computer screen, should be shielded from inappropriate viewing.

- Complete records must be kept for each patient. If a patient returns in the future for *follow-up* scans, the positioning, acquisition parameters, and placement of the ROIs must be reproduced as closely as possible to the original scans. Thus the technologist should keep a log sheet with the patient's identifying information and date, the file name, and the archive location of each scan. The log should also identify any special information about why particular scans were or were not performed (e.g., the right hip was scanned because the left hip was fractured, or the forearm was not scanned because of the patient's severe arthritis) and any special procedures taken for positioning (e.g., the femur was not fully rotated because of pain) or scan analysis (e.g., the bone edge was manually placed for the radial ultradistal region). The patient questionnaire, log sheet, and complete scan printouts should be stored in an accessible location. All scan archive media must be clearly labeled and accessible.
- The general consensus is that DXA scan results should be kept on file indefinitely.

## COMPUTER COMPETENCY

DXA scan acquisition, analysis, and archiving is controlled with a personal computer (PC). Therefore DXA technologists must be familiar with the basic PC components and how they work, such as the disk drives (hard, floppy, and optical), keyboard, monitor, printer, and mouse. Newer DXA software runs on the Windows operating system, as opposed to DOS. Technologists working on DOS-based systems must know how to exit to DOS and use basic commands to change paths, check a directory, and copy files to disk. Windows-based software tends to be more user friendly and requires the use of a mouse to point, click, and/or drag. Technologists will need to upgrade their computer skills as DXA software and hardware are enhanced to allow communication between scanners and digital imaging systems via multimedia and networking capabilities. This allows a scan to be performed at one location and then be sent electronically to a remote location for reading or review by an interpreting or referring physician.

It is essential that the technologist be able to backup, archive, locate, and restore patient scan files. Daily backup and archival is recommended to preserve patient scan files and data. A third copy of data should be stored offsite to ensure retrieval of patient data, as well as to be able to rebuild databases, if there is a computer failure, fire, flood, or theft.

Frequently manufacturers will upgrade software versions and the technologist is responsible to perform this task. Records of upgrades and software installation should be maintained. Current software media should be accessible to service engineers at time of preventive maintenance and repairs.

Computers consist of software and hardware.<sup>1</sup> Software consists of programs written in code that instruct the computer how to perform tasks. The DXA manufacturer's software controls many aspects of DXA scanning from starting the scan to calculating and reporting the results. Hardware comprises the physical components for central processing, input, output, and storage.

<sup>1</sup>Following the introduction of the computer in medicine, the practice and development of radiologic procedures rapidly expanded. In bone densitometry, the computer assisted in major advancements. Due to space considerations in this edition of *Merrill's Atlas*, the "Computer Fundamentals and Applications in Radiology" chapter has been deleted. For those interested in learning more about computer fundamentals, please see Volume 3, Chapter 32 of the eighth or ninth editions of this Atlas.

## DXA SCANNER LONGITUDINAL QUALITY CONTROL

*Longitudinal quality control* procedures are performed on a regular basis, usually at least three times a week and always before the first patient scan of the day. The procedures either perform external calibration or track the calibration over time. Manufacturers' instructions in the Operator's Manual must be followed exactly. Lunar and Norland systems require scanning a block to perform external calibration. The technologist must check a report to note whether or not the system passed all tests of internal parameters (Fig. 39-17). These manufacturers also provide semi-anthropomorphic phantoms for tracking calibration over time. Hologic systems do not require calibration scans, but they do require tracking calibration by regular scanning of a Hologic anthropomorphic spine phantom, plotting the BMD, and checking statistical and quality control rules (e.g., CV less than or equal to 0.60%). These procedures have the common goal of ensuring that patients are scanned on properly functioning equipment with stable calibration. Unstable calibration can take the form of abrupt shifts or slow drifts in BMD, as seen on plots of phantom scan results (Fig. 39-18). These problems make the patient's BMD values too high or too low and prohibit a valid comparison between baseline and follow-up scans.



The quality control rule used to check DXA scanners is modified from Shewhart Control Chart rules. Shewhart rules are a classic method of checking that a quality parameter is stable and within acceptable limits. The mean and SD are calculated from the first 25 measurements of the parameter. A chart is created with the mean in the middle and control limits 3 SDs above and below the mean. The parameter measurements are plotted over time and checked for violation of rules, such as one measurement more than 3 SDs from the mean. For DXA the value of the control limits is modified to 1.5% of the mean, to provide more uniformity across scanners. The classic DXA control chart is the mean in the middle with control limits (1.5% of the mean) above and below. This chart and plot is produced automatically by the Hologic software (see Fig. 39-15). For other manufacturers, the chart and plotting must be done by hand. When the phantom BMD value falls outside the control limits, the scan should be repeated up to 2 more times. If the BMD remains outside the control limits the manufacturer should be contacted and no patients should be scanned until the equipment has been cleared for further use.

Five to 10 phantom scans should be performed and plotted before and after scanner preventive maintenance, repair, relocation, and software or hardware upgrade to check whether the calibration has been affected. Sometimes the service person will perform these scans.

Inconsistent phantom scanning, analysis, and/or interpretation of the results may cause the calibration to appear unstable when it is actually stable. It is of utmost importance that the DXA technologist understands the quality control procedures and follows them consistently. DXA labs should have written procedures and documented instructions to ensure consistency within and among technologists.

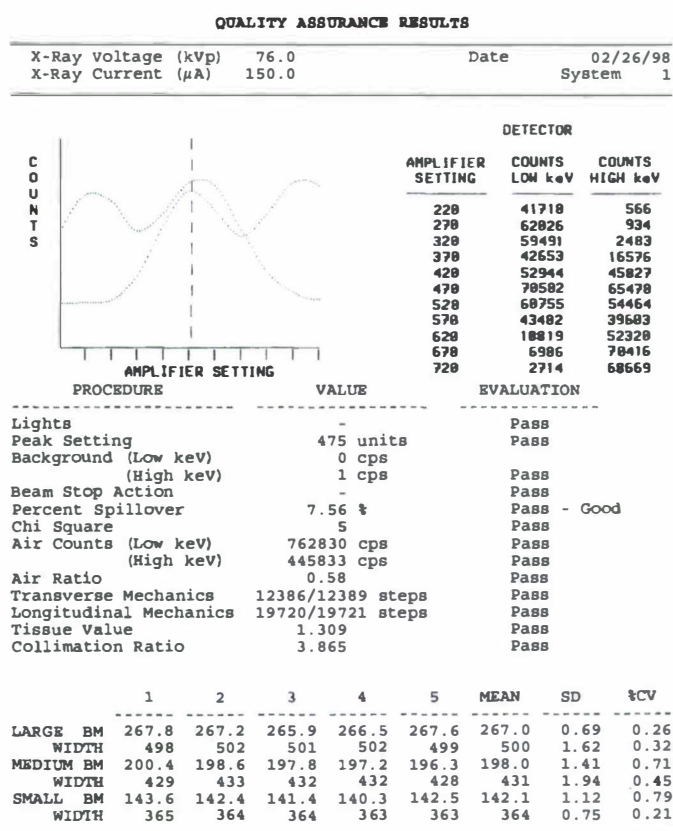


Fig. 39-17 Lunar quality assurance report. This scanner passed all tests. At the bottom, values from the last five scans are averaged for calibration purposes.

(Courtesy GE-Lunar, Madison, Wis.)

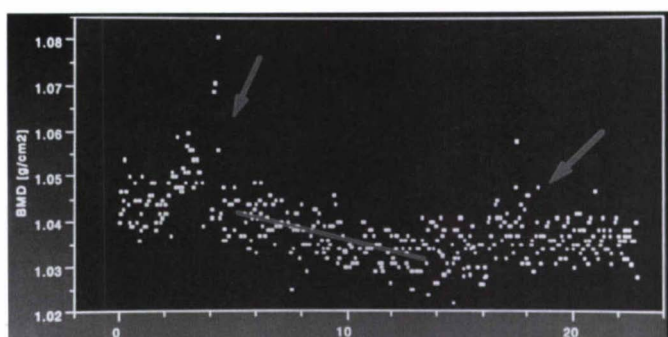


Fig. 39-18 Plot of spine phantom BMD and time (in months). The two arrows show abrupt shifts in BMD. The straight line shows a slow drift downwards in BMD. These indicate changes in scanner calibration.

## ANATOMY, POSITIONING, AND ANALYSIS

Radiologic technologists receive extensive instruction in anatomy during their professional education. DXA scanning requires knowledge of specialized aspects of anatomy that relate to properly positioning the patient for scanning and the ROI for scan image analysis. The points presented in this section generally apply to all DXA scanners; however, instruction from the particular scanner's manufacturer is required before the scanner is used. The operator's manual that accompanies the equipment is the ultimate authority.

Like all technologies, DXA has operating limits. Accuracy and precision may be impaired if the bone mass is very low, the patient is too thick or thin, the anatomy is abnormal, or there have been significant changes in soft tissue between serial scans. The added value of experienced DXA technologists is that they can recognize and adapt to abnormal situations and they know the ultimate limits of the technology. All abnormalities that might compromise the scan results in an individual patient must be noted by the technologist and taken into consideration by the reporting physician.

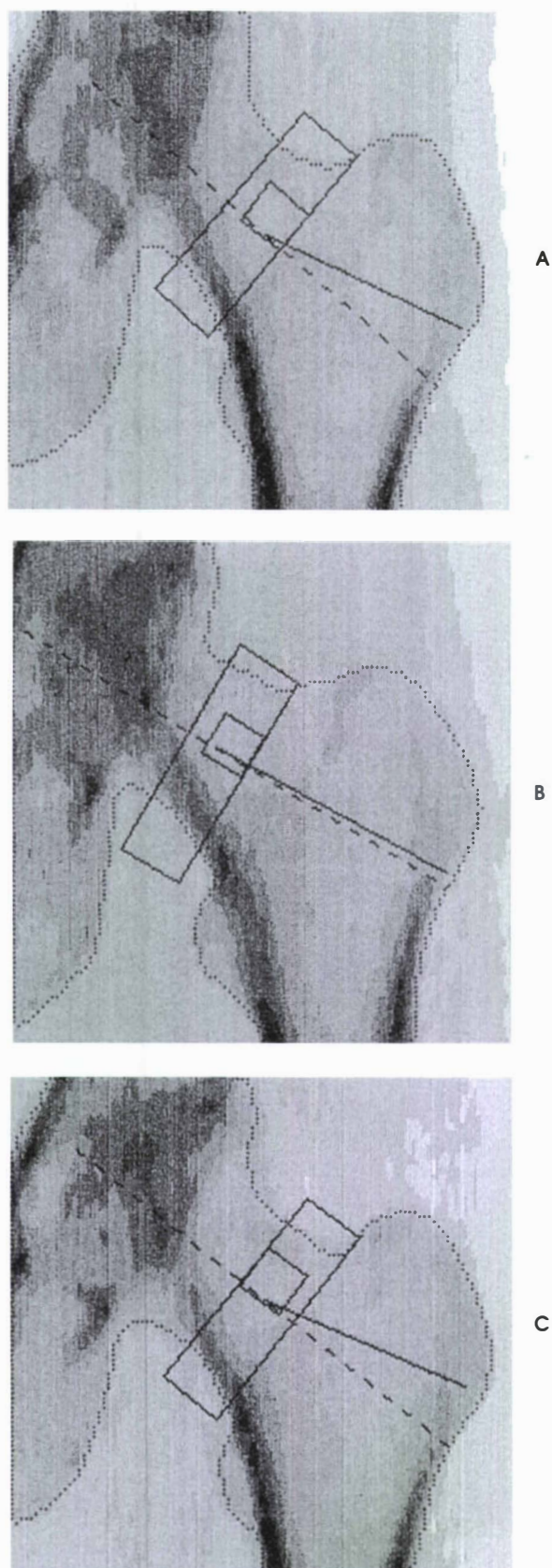
It is also important to remember that DXA calculations are based on soft tissue, as well as bone. Adequate amounts of artifact-free soft tissue are essential for valid results.

## Follow-up scans

The BMD of a patient may be followed over time. Direct comparison of BMD results requires that follow-up scans be performed on the same scanner that was used for the baseline scans or at least on a scanner of the same manufacturer that has been calibrated to the baseline scanner. BMDs obtained by scanners from different manufacturers cannot be directly compared, nor can BMDs obtained by using different technologies, such as DXA and QCT.

It is imperative that the patient positioning be exactly the same for the baseline and follow-up scans, that the same scan settings are used (e.g., field size, mode, or speed and current), and that the ROIs are placed identically on the images. These steps ensure that scan results are comparable over time. To accomplish this, the DXA technologist should have the baseline printouts available and should use the software's *compare feature*, if recommended by the manufacturer. All extraordinary measures taken for positioning and analysis for the baseline must be documented and available for use when performing follow-up scans.

Fig. 39-19 shows the comparison of a patient's hip scans from 1995 (Fig. 39-19, A) and 2001 and is an example of why follow-up positioning must match baseline if the BMDs are to be compared. The first follow-up scan (Fig. 39-19, B) did not reproduce the baseline positioning. The rotation of the femoral neck was different as indicated by the larger lesser trochanter and the femoral body was more abducted. This resulted in the midline being placed differently by the software and therefore a different angle for the neck ROI. The scan was repeated (Fig. 39-19, C) to correctly reproduce the baseline positioning. The difference in Total hip BMD between scans A and B is  $-13\%$  compared to a difference of  $-10\%$  between scans A and C.



**Fig. 39-19** Example of incorrect and correct follow-up scan positioning. Note the difference in BMD between the scans. **A**, Baseline hip scan. **B**, Incorrectly positioned follow-up scan. Size and shape of lesser trochanter and angle of femoral body do not match baseline. **C**, Correctly positioned follow-up scan.



### Lumbar spine

Spine scans are most appropriate for predicting vertebral fracture risk in patients less than 65 years of age because degenerative changes in the elderly elevate spinal BMD, giving a false underestimate of fracture risk. The following points can help in positioning patients for AP lumbar spine DXA scans, analyzing the scan results, and evaluating the validity of the scans:

1. Degenerative changes in the spine, such as *osteophytosis*, scoliosis greater than 15 degrees (Fig. 39-20), overlying calcification, and compression fractures (Fig. 39-21) falsely elevate the BMD. Artifacts in the vertebral bodies or very dense artifacts in the soft tissue also affect the BMD. The supervising physician should set policies for dealing with these problems.
2. Generally the spine is centered in the scan field. In a patient with scoliosis, L5 may need to be off center so that adequate and relatively equal amounts of soft tissue are on either side of the spine throughout the scan.
3. Several lines of iliac crest should be included in the scan. This ensures the inclusion of all of L4. The iliac crest is an excellent landmark for consistent placement of the intervertebral markers at baseline and follow-up scanning.
4. The AP spine scan image displays primarily the vertebral posterior elements, which have characteristic shapes. These shapes can be used to place the intervertebral markers and label the vertebral levels when degenerative disease has obscured the intervertebral spaces. L1, L2, and L3 have a Y shape, L4 has an H or X shape and appears to have "feet", and L5 looks like a sideways I or "dog bone" (Fig 39-22). Other clues are that L3 commonly has the widest transverse processes, L1, L2, and L3 are approximately the same height and L4 is a little taller than the others, and the iliac crest usually lies at the level of L4-L5 intervertebral space.

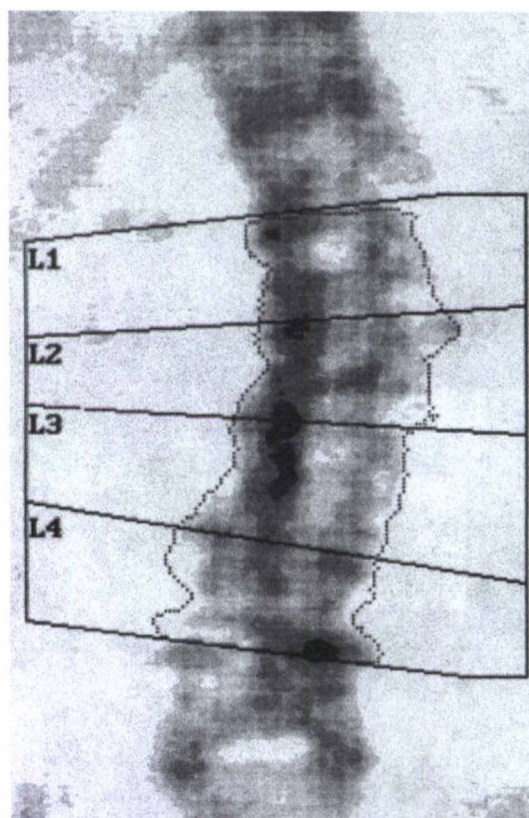
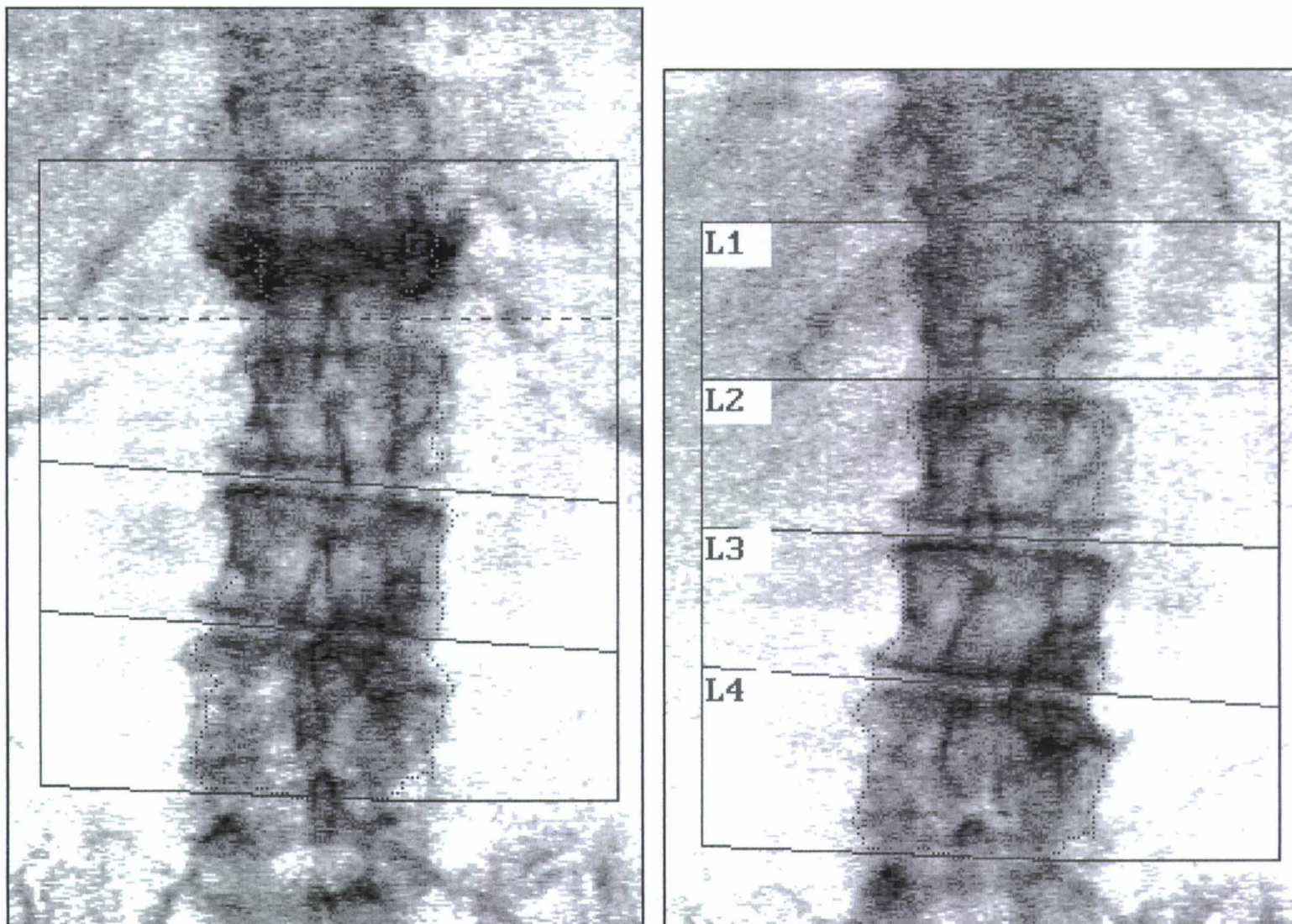
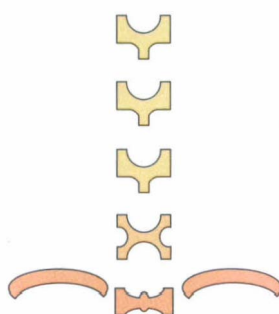


Fig. 39-20 DXA AP spine scan with scoliosis and scoliosis analysis technique.



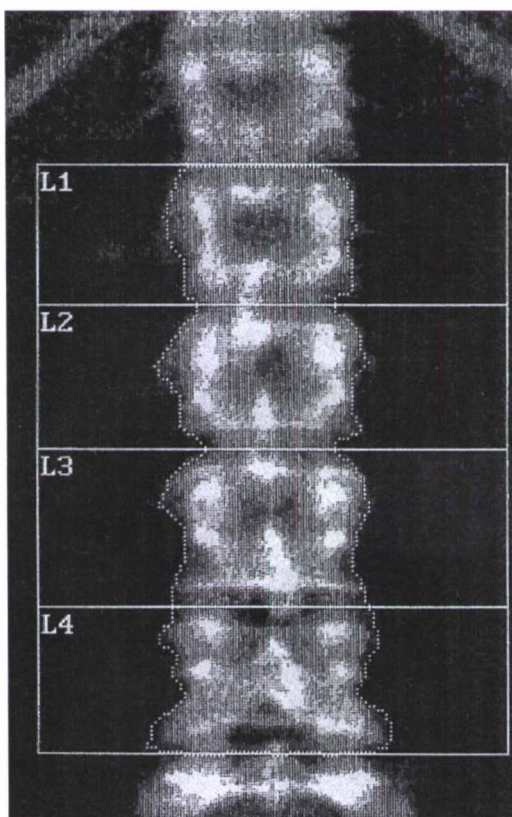
**Fig. 39-21** Use of Hologic compare feature indicates that L1 bone map and ROI from baseline scan (*right*) no longer fits the follow-up scan (*left*) because of a compression fracture of L1. Both scans should be analyzed to exclude L1 before comparing Total BMD.



**Fig. 39-22** Characteristic shapes of L1-L5 and their relationship to the iliac crests as seen on a DXA AP spine scan.



5. A small percentage of patients appear to have four or six lumbar vertebrae rather than five, which is most commonly seen. The vertebrae can be labeled by locating L5 and L4 based on their characteristic shapes and then counting up (Fig. 39-23). The procedure of counting from the bottom superiorly biases towards a higher BMD and avoids including T12 without a rib, which significantly lowers the BMD. This procedure ensures a conservative diagnosis of low BMD.
6. Only if absolutely necessary should the bone edges be adjusted or the intervertebral markers angled. If used, these techniques should be performed in a manner that will be easy to reproduce at follow-up scanning.
7. Check that the patient is lying straight on the table by looking from the head or foot end of the table. If a patient is lying straight on the table but the spine is not straight on the scan, do not attempt to twist the patient to get the image straight. This unusual positioning will not be reproducible at follow-up. Make a note in the record that the patient was positioned straight on the table.
8. The leg block reduces the lordotic curve and opens up the intervertebral spaces. Be consistent about using the longer or shorter end of the leg block when a patient returns for follow-up.
9. A basic check list for a good AP spine scan (see Fig. 39-21, baseline scan) includes the following:
  - The spine is straight and centered in the scan field. Note that patients with scoliosis should have relatively equal amounts of soft tissue on either side of the spine.
  - The scan contains a few lines of the iliac crest and half of T12; the last set of ribs is shown.
  - The entire scan field is free of external artifacts.
  - The intervertebral markers are properly placed, and vertebral levels are properly labeled.
  - The bone edges are reasonably placed.



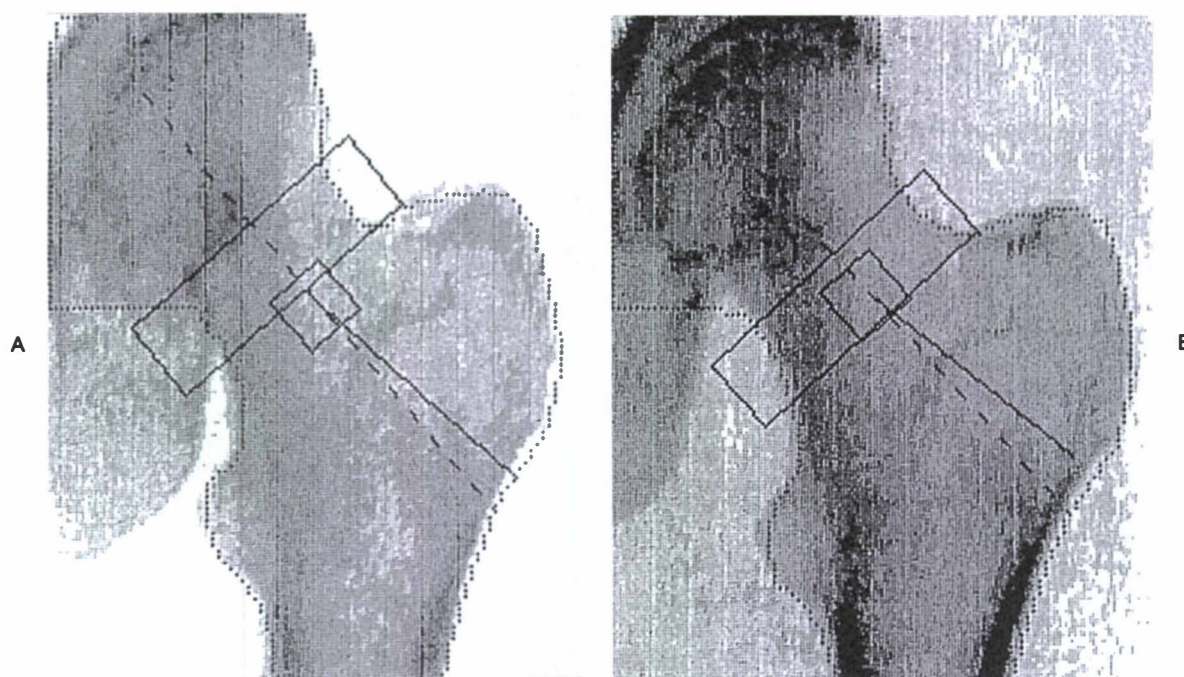
**Fig. 39-23** Six lumbar vertebrae. Note that the vertebral labeling is done from the bottom to the top according to the shape of the vertebrae.



### Proximal femur

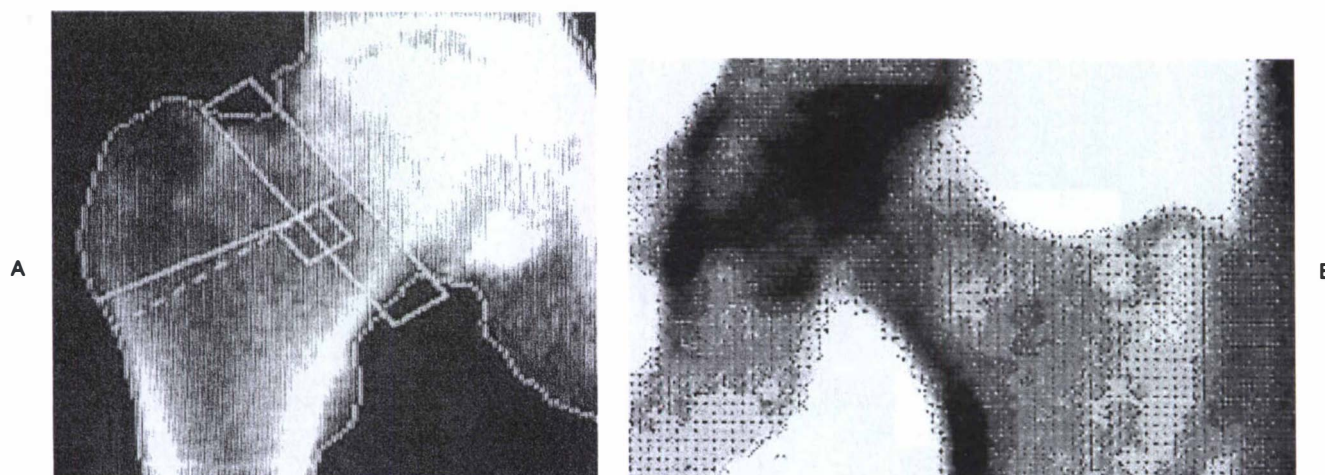
The hip scan is perhaps the most important because it is the best predictor of future hip fracture, which is the most devastating of the fragility fractures. Compared with the spine scan, the hip scan is more difficult to perform properly and precisely because of variations in anatomy and the small ROIs. The following points can help in positioning patients for hip DXA scans, analyzing the results, and evaluating the validity of the scans:

1. With the patient in a supine position, the hip must be rotated 15 to 25 degrees medially to place the femoral neck parallel with the tabletop and perpendicular to the x-ray beam. A clue to successful rotation is the lesser trochanter is diminished in size and only slightly visible (or not visible); a large, pointed lesser trochanter indicates too little rotation (see Fig. 39-19, B, C). All scanners come with positioning aids that should be used according to manufacturers' instructions.
2. The body of the femur must be straight or, in other words, parallel with the long axis of the table. Because the lateral edge of the femoral body is not straight, it is best to imagine a straight line through the center of the body and verify that this line is parallel with the lateral edge of the scan field.
3. A few patients have little or no space between the ischium and femoral neck. In some cases, part of the ischium lies under the neck, elevating the BMC and thus falsely elevating the femoral neck BMD (Fig. 39-24, A). This might be caused by the ischium (pelvis) being rotated. Try having the patient sit up, move a little, and lie back down for repositioning (Fig. 39-24, B). If the problem still exists, slightly over abduct the leg until the ischium and neck are separated. Some software allows "cutting out" the ischium, but this will not resolve the problem of ischium underlying the femoral neck.
4. In order to compare hip BMD over time the positioning must be exactly reproduced and the angle of the neck box ROI must be the same (see Fig. 39-19). Check these points on the baseline and follow-up images:
  - The lesser trochanter must be the same size and shape. If not, change the hip rotation. More rotation will make the lesser trochanter appear smaller.
  - The femoral body must be abducted the same amount. If not, abduct or adduct the leg as needed.
  - The neck box ROI is automatically placed perpendicular to the midline so the midline must be at the same angle in each scan. If it is not, check positioning and reposition as required. If positioning is not the problem, on Hologic scans check the femoral neck bone edge for bumps or notches and adjust the bone edge as needed. As a last resort, manually rotate the midline to match on both scans.



**Fig. 39-24** **A**, Despite use of the software tool to "cut out the ischium", bone from the ischium underlies the femoral neck ROI. The BMC will be increased thereby increasing the BMD. **B**, One year later the same patient was positioned for a follow-up scan. The pelvis is no longer rotated as indicated by the narrower width of the ischium. There is now adequate space between the neck and ischium and no ischium beneath the neck ROI. This is an example of poor pelvis positioning in A; the patient must be lying flat on the pelvis as in B. These two scans can NOT be compared for rate of bone loss. The scan in B should be considered a new baseline and be compared to a properly performed follow-up scan in the future.

5. Some manufacturers provide dual-hip software that scans both hips without repositioning. If only one hip can be scanned, the non-dominant hip is preferred (usually the left). However, scoliosis, diseases that cause unilateral weakness (e.g., polio, stroke), or unilateral osteoarthritis of the hip may cause left-right differences. If arthritis is present, the less affected hip should be scanned because arthritis can cause increased density in the medial hip and shortening of the femoral neck (Fig. 39-25, A). In cases of unilateral disease, scan the less affected hip. A fractured or replaced hip with orthopedic hardware should not be scanned.
6. For Lunar scans, no air should be present in the ROI because it will cause an incorrect soft tissue reading and thus affect the BMD. Air is a problem in small- to medium-size patients who do not have adequate soft tissue lateral, anterior and/or posterior to the proximal femur. Use tissue equivalent bags properly and consistently. The Lunar femur scan in Fig. 39-25, B, was performed with air in the lateral scan field. Furthermore, the scan does not include several scan lines below the inferior edge of the ischium.
7. The limits of the technology are taxed by patients with extreme thinness or thickness and/or very low bone mass. These problems are revealed by poor bone edge detection and/or a mottled or "moth eaten" appearance of the image. Use the fastest speed for thin patients and the slowest speed for thick patients. Some images show the bone edges, and it is obvious when the proper edge cannot be detected. For images that do not show the bone edges, the area values must be checked and compared. A very large *Ward's triangle* area or a very small trochanter area is a clue that the bone edges are not being properly detected. The operator's manual may not adequately cover these problems. It is the responsibility of the technologist to recognize the problems and query the manufacturer's applications department about the best ways to handle such difficulties. If a patient is deemed unsuitable for a DXA hip scan, a physician can suggest alternative scans at other anatomic sites using DXA or other technologies.
8. A basic checklist for a good DXA hip scan (see Fig. 39-19, A) includes the following:
  - The lesser trochanter is small and round or can not be seen.
  - The midline of the femoral body is parallel to the lateral edge of the scan.
  - Adequate space is present between the ischium and femoral neck.
  - The midline through the femoral neck is reasonably placed resulting in a reasonable angle for the femoral neck box.
  - If the bone edge is visible, it is properly placed; else the area values are reasonable.
  - The proximal, distal, and lateral edges of the scan field are properly located.
  - No air is present in the scan field on Lunar scans.



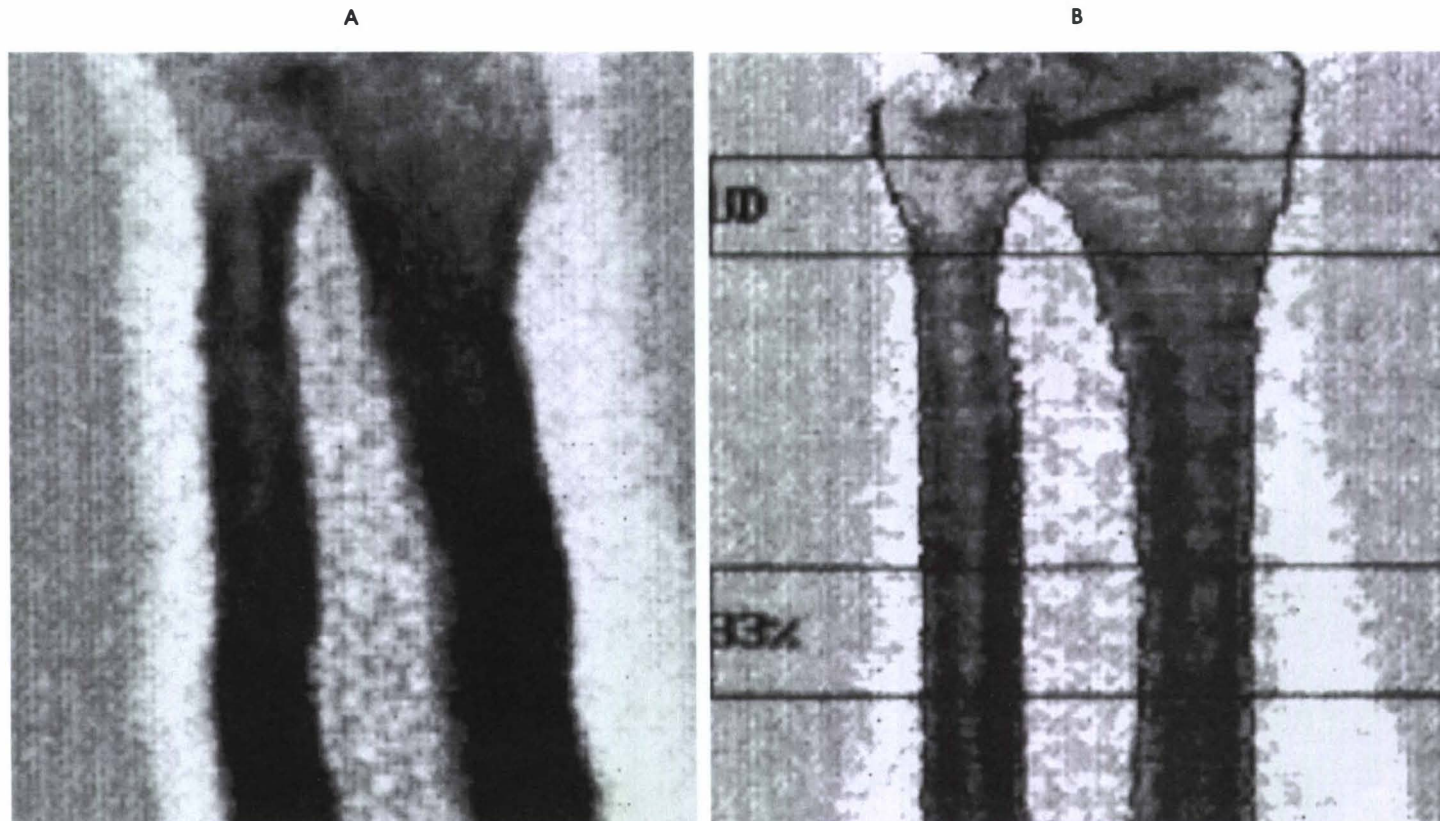
**Fig. 39-25** DXA femur scans. **A**, Hip arthritis. Note the increased density in the medial hip and the foreshortened femoral neck. **B**, Lunar scan with air in the lateral scan field. This scan should be repeated placing a tissue equivalent bag lateral to the hip. On very thin patients, place a second bag on top of the hip. Always be sure there are no air spaces between the bags and the body.



## Forearm

Two important ROIs are present on the DXA forearm scan: the ultradistal region, which is the site of the common Colles fracture; and the one-third (33%) region, which measures an area that is primarily cortical bone near the midforearm (see Table 39-1). Although the ulna is available for analysis, only the radius results are usually reported. The following points can help in positioning patients for forearm DXA scans, analyzing the scan results, and evaluating the validity of the scans:

1. The nondominant forearm (usually left) is generally scanned because it is expected to have slightly lower BMD than the dominant arm. A forearm should not be scanned in patients with a history of wrist fracture, internal hardware, or severe deformity resulting from arthritis. If both forearms are unsuitable for scanning, other anatomic sites should be considered.
2. At the time of the initial scan, the forearm should be measured according to the manufacturer's instructions. Usually the ulna is measured from the ulna styloid to the olecranon process. The distal one third of this measurement is used to place the one-third or 33% ROI. The baseline measurement should be noted and then used again for follow-up scans to ensure placing the one-third region at the same anatomic point on every scan. The directions for determining the starting and ending locations of the scan must be followed exactly (Fig. 39-26, A). A common problem is that a scan is too short in the proximal direction, which makes it impossible to place the one-third region properly.
3. The forearm must be straight and centered in the scan field (see Fig. 39-26, A). This is the only scan that requires adequate amounts of air in the scan field. Soft tissue must surround the ulna and radius, and several lines of air must be present on the ulnar side. If the forearm is very wide, the scan must be manually set for a wider scan region so that adequate air is included.
4. Motion is a common problem (see Fig. 39-26, A). The patient should be in a comfortable position so that the arm does not move during the scan. The hand and proximal forearm can be secured with straps or tape placed outside the scan field. Avoid unnecessary conversation during the scan to minimize movement. The same chair should be used for all patients to ensure consistency over time. The chair should have a back but no wheels or arms.



**Fig. 39-26** DXA forearm scans. **A**, This DXA forearm scan demonstrates several positioning and acquisition mistakes; the distal ends of the radius and ulna are cut off, indicating the scan was started too proximally; the forearm is not straight or centered in the scan field; and motion has occurred in the proximal radius and ulna. **B**, This scan demonstrates good patient positioning, scan acquisition, and scan analysis.



5. Historically, the placement of the ultra-distal ROI has varied according to several different protocols. One popular method is to manually place the distal end of the ROI just below the radial endplate. This placement is easy to replicate on follow-up scans. The ultra-distal ROI is subject to low BMD, creating bone edge detection problems. The bone edge should be carefully checked and manually adjusted if needed. Baseline and follow-up bone edges must match in order to avoid changes in BMD due solely to area changes caused by inconsistent bone edge detection.
6. A basic checklist for a good DXA forearm scan (Fig. 39-26, B) includes the following:
  - The forearm is straight and centered in the scan field. Adequate amounts of soft tissue and air are included.
  - No motion occurs.
  - The proximal and distal ends of the scan field are properly placed.
  - Bone edges are properly and consistently placed.
  - No artifacts, such as watches or bracelets, are present in the scan field.

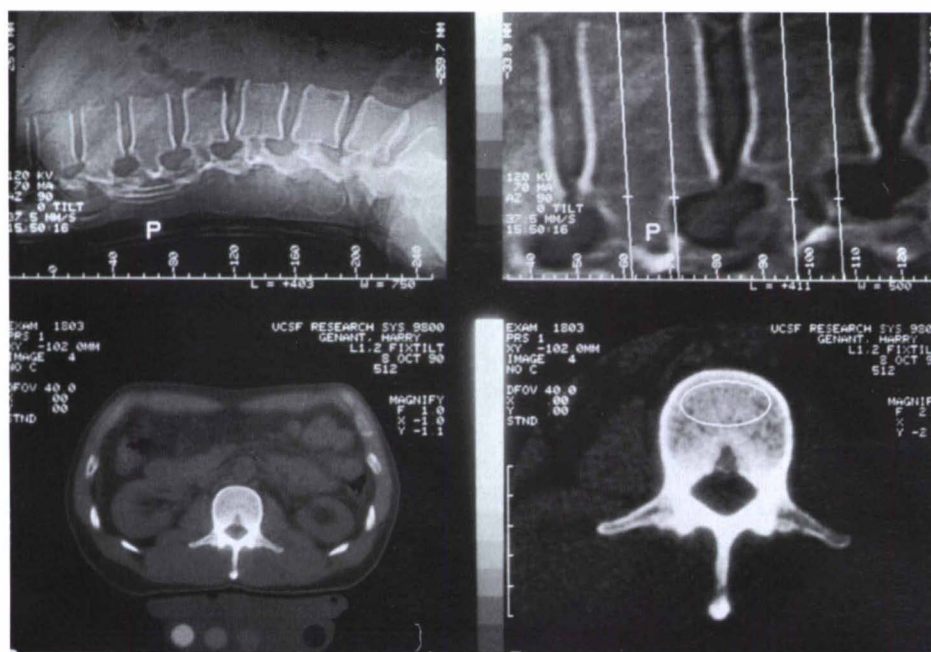
## Other Bone Densitometry Techniques

### CENTRAL (OR AXIAL) SKELETAL MEASUREMENTS

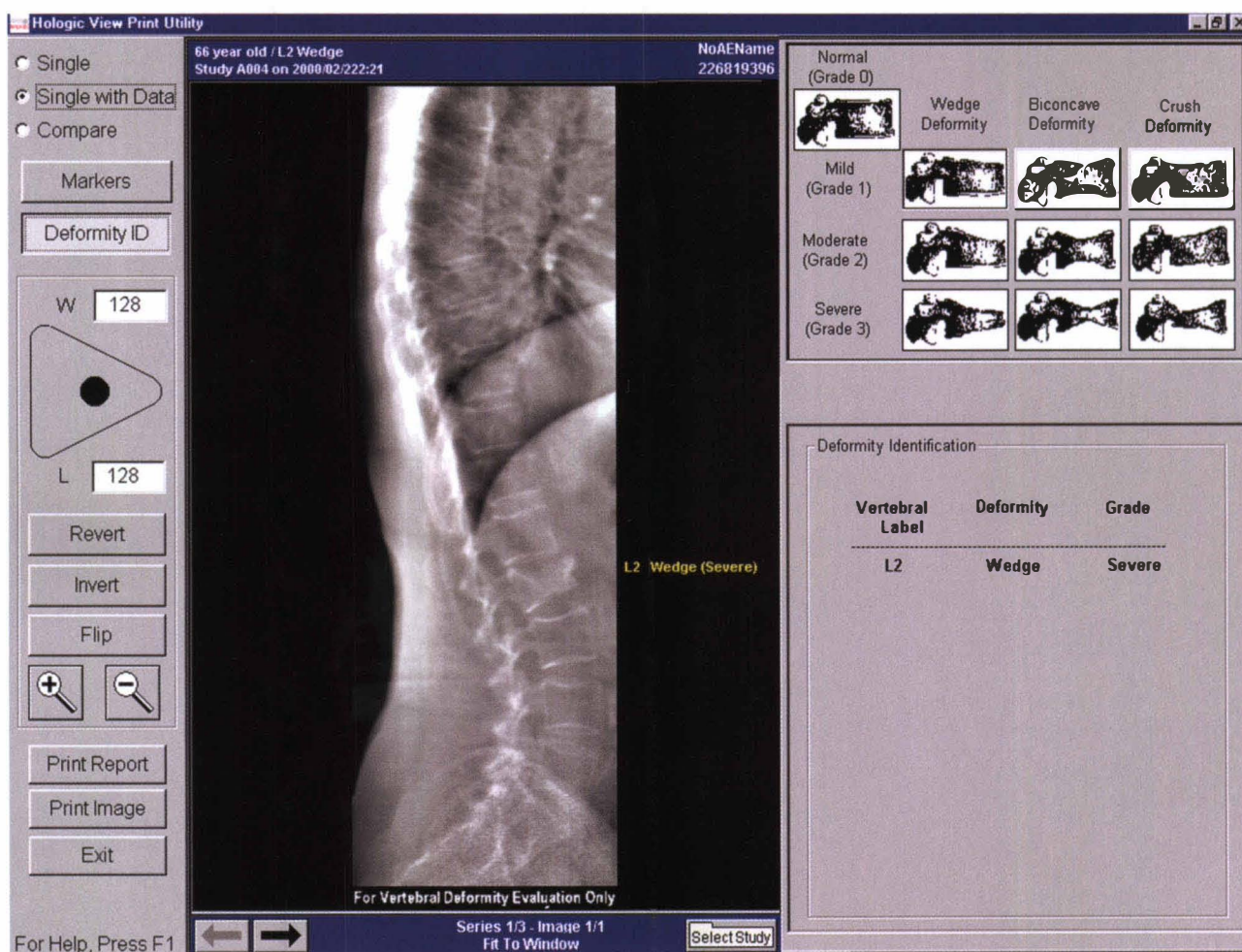
*Quantitative computed tomography (QCT)* is an established method using cross-sectional CT images from commercial scanners equipped with QCT software and a bone mineral reference standard. QCT has the unique ability to provide separate BMD measurements of trabecular and cortical bone and true volumetric density measurements in grams per cubic centimeter ( $\text{g}/\text{cm}^3$ ). QCT of the spine is used to measure the trabecular bone within the vertebral bodies to estimate vertebral fracture risk and age-related bone loss; it is also used for the follow-up of osteoporosis and other metabolic bone diseases and their therapies (Fig. 39-27). Other current uses of QCT involve measuring BMD at the hip and producing high-resolution three-dimensional images to analyze trabecular bone architecture.

Lateral lumbar spine DXA scans can be performed with the patient in the supine position with scanners that have C-arms (see Fig. 39-12). Decubitus lateral scans are obtained with fixed-arm scanners. Lateral spine DXA allows partial removal of the outer cortical bone and thus gives a truer measurement of the inner trabecular bone, which experiences earlier bone loss and is more responsive to therapy (see Fig. 39-9). However, lateral spine DXA is often confounded by superposition of the ribs and iliac crest with the vertebral bodies and has poorer precision than AP spine DXA. Lateral DXA is not widely used in clinical practice.

A more common use for lateral scans is *morphometric x-ray absorptiometry (MXA)*. This utilizes SXA (for image only) or DXA (for image and BMD) lateral scans of the thoracic and lumbar spines from the level of about T4 to L5 (Fig. 39-28). The images are used to determine vertebral shape abnormalities that may indicate vertebral fragility fractures which are a strong risk factor for future vertebral fractures. The upper right corner of Figure 39-28 shows the Genant grading system. The 3 columns on the right show the types of fracture and the rows show the grades of severity. It is easy to see a severe fracture and relatively easy to see a moderate fracture, but it is difficult to determine if a mild deformity is normal for the patient or the beginning of a problem. Also, vertebral fractures may have occurred earlier in life from trauma, such as automobile accidents or heavy lifting, or from degenerative arthritis; these are not fragility fractures that predict future fracture. For these reasons, MXA scans should only be read and reported by educated interpreters.



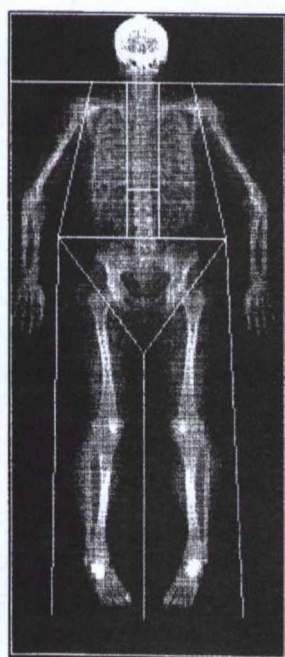
**Fig. 39-27** Examples of various elements of a QCT examination: *upper left*, lateral scout image of lumbar spine; *upper right*, localizer lines for midvertebral slices through L1 and L2; *lower left*, CT slice showing the calibration phantom below the patient; *lower right*, elliptic ROI positioned in the trabecular bone of the vertebral body.



**Fig. 39-28** MXA scan to detect vertebral shape abnormalities. The Genant grading system is in the upper right corner.

(Courtesy Hologic, Inc., Bedford, Mass.)





Region	Fat (grams)	Lean+BMC (grams)	% Fat (%)
L Arm	1230.3	2528.5	32.7
R Arm	1105.0	2790.3	28.4
Trunk	9281.2	25315.1	26.8
L Leg	4643.2	8616.7	35.0
R Leg	4531.4	8389.8	35.1
SubTot	20791.1	47640.4	30.4
Head	868.6	3480.3	20.0
TOTAL	21659.7	51120.6	29.8

Fig. 39-29 Hologic DXA whole-body scan with partial printout of body composition results. The percent body fat (% Fat) is reported at the right.

Whole body DXA measures bone mass (i.e., area, BMC, BMD) and *body composition* for the total body and subregions of the body (e.g., arms, legs, trunk). Body composition can be measured as fat and fat-free mass (with or without BMC) in grams or percent body fat (Fig. 39-29). Careful positioning is required to separate the bones of the forearm and lower leg. Obese patients present a problem when not all of the body will fit in the scan field. The ROIs must be carefully placed according to manufacturers' instructions. It is not unusual to have internal or external artifacts that can not be removed and the effect of such artifacts depends upon size, density, and location. For example, hip joint replacement hardware will have more effect than a woman's thin wedding band. Each DXA lab should have written procedures so all patients are scanned and analyzed consistently. All deviations from normal and artifacts should be noted for the interpreting physician. Whole body DXA data are useful for studying energy expenditure, energy stores, protein mass, skeletal mineral status, and relative hydration. These measurements have been used in research studies and clinical trials of, among others, osteoporosis therapies, obesity and weight change, fat and lean distribution, and diabetes. Clinically, whole body scans are used routinely in pediatrics and for body fat analysis in athletes and patients with underweight disorders (e.g., anorexia nervosa).

Pediatric DXA is truly in its infancy, but it is possible to make some general statements. The diagnostic capabilities of most scanners start with age three to five and some use separate pediatric and adult databases. Experts recommend a whole body scan, as well as spine and/or hip, and use of BMC to overcome artifacts resulting from bone size. The technologist must carefully ensure that the correct parameters are selected on the machine, such as speed, current, and pixel size. Because pediatric patients haven't reached peak bone mass, interpreters report the Z-score instead of the T-score. This compares patients to their physical and chronological peers.

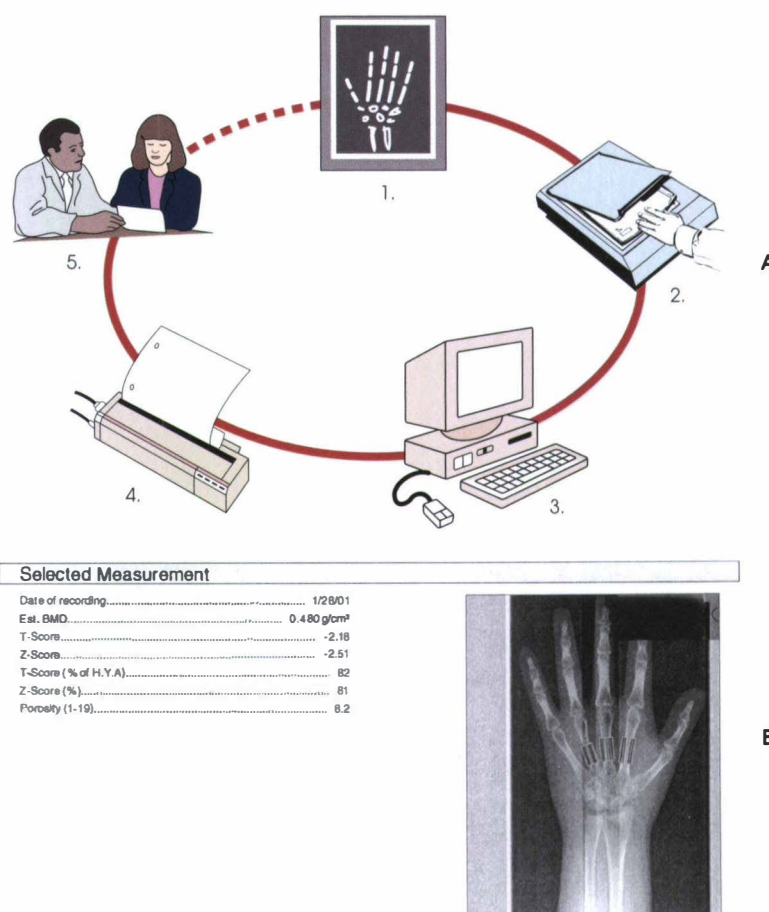
In addition to measuring bone mineral, DXA systems have been used for geometric measurements of the hip. The *hip axis length (HAL)*, defined as the distance along the femoral neck axis from the base of the greater trochanter to the inner pelvic brim, has been identified as an independent indicator of hip fracture risk. Based on results from the Study of Osteoporotic Fractures, each SD increase in HAL (about 6 mm) approximately doubles the risk for hip fracture. At this time HAL is predominantly used as a research tool. Hopefully future research will define the clinical role of HAL for assessing fracture risk along with other risk factors.



## PERIPHERAL SKELETAL MEASUREMENTS

Peripheral bone density measurements include scans at the hand, forearm, heel, and tibia. Other skeletal sites are being investigated. The scanners are smaller, some even portable, making the scans more available to the public and less expensive than conventional DXA. Peripheral measurements can predict *overall risk of fragility fracture* to the same degree as measurements at central skeletal sites but are not generally accepted for following skeletal response to therapy.

Radiographic absorptiometry (RA) is a modern adaptation of the early bone density technique. Digital RA utilizes a hand radiograph that is scanned (digitized) into a computer (Fig. 39-30, A). ROIs are placed on the digital image of the metacarpals and estimated BMD is reported (Fig. 39-30, B).

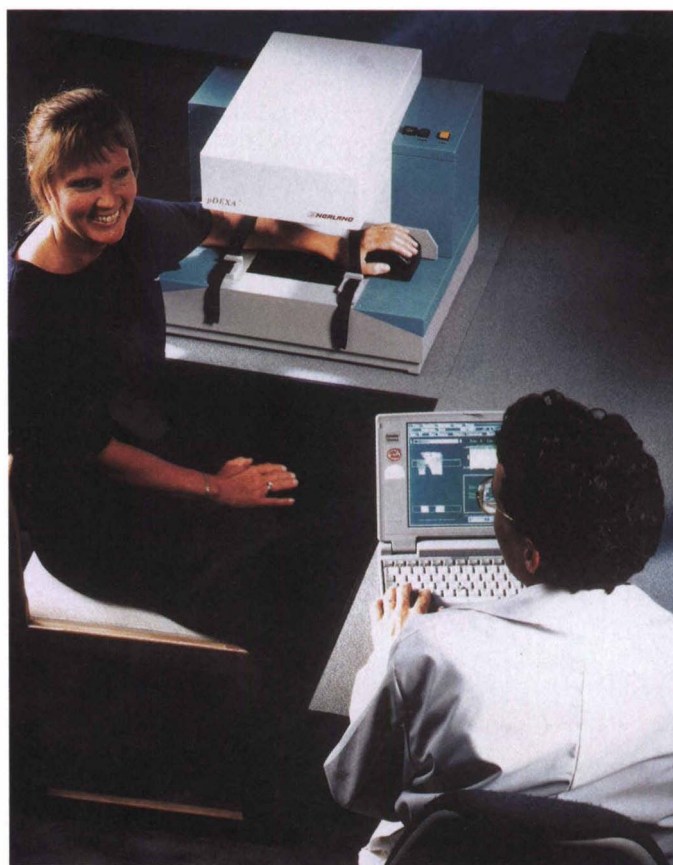


**Fig. 39-30** Pronosco X-posure System for digital BMD estimates. **A**, The 5 steps of acquiring and digitizing a standard hand x-ray, keying in patient data, receiving a printout, and discussing results with the patient. **B**, A partial report showing the automatically placed ROIs on the metacarpals, estimated BMD, T- and Z-scores, and a unique porosity measurement.

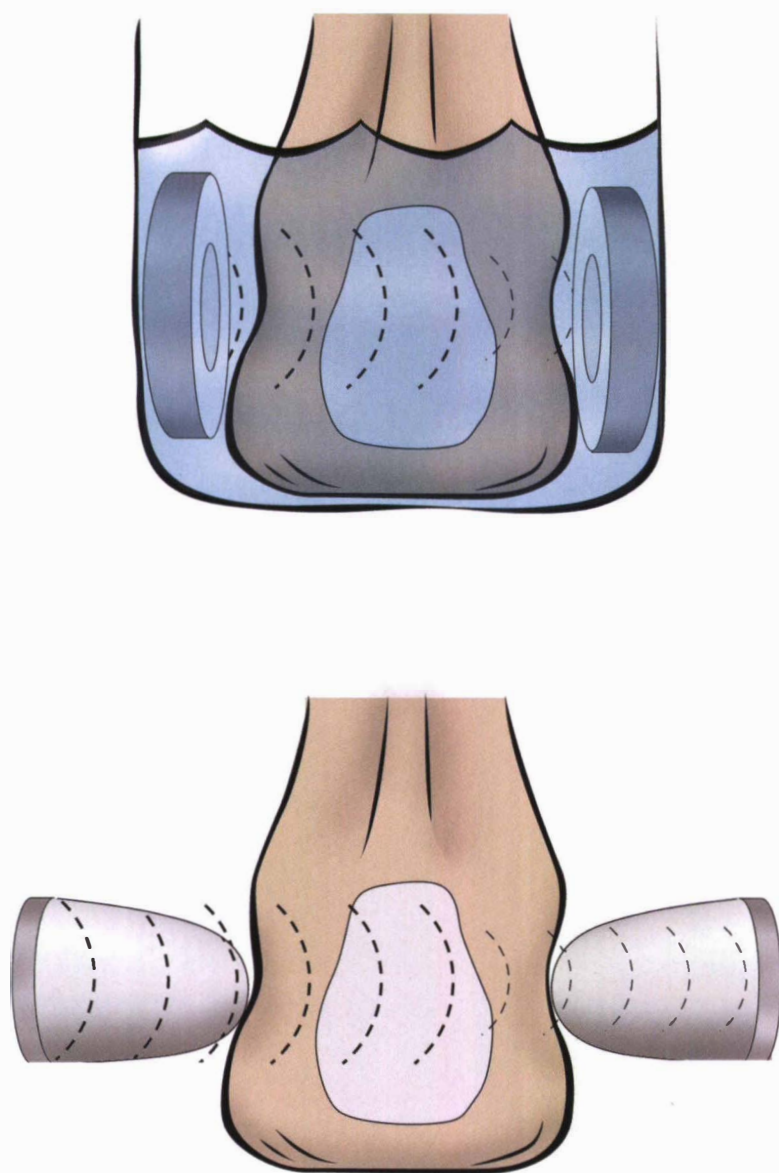
(Courtesy Pronosco A/S, Vedbaek, Denmark.)

*Single energy x-ray absorptiometry (SXA), peripheral dual energy x-ray absorptiometry (pDXA), and peripheral quantitative computed tomography (pQCT)* are adaptations of DXA or QCT for measuring the thinner, easier-to-penetrate, peripheral skeletal sites. Most scanners measure the wrist (Fig. 39-31) or the heel.

With *quantitative ultrasound (QUS)* of the heel, ultrasound waves are transmitted laterally through the calcaneus using either water or gel (dry system) as a coupling medium (Fig. 39-32). Attenuation increases as the velocity of the ultrasound waves increases, and normal bone attenuates more than osteoporotic bone. These properties of bone and ultrasound signals permit the assessment of the QUS parameters of Broadband Ultrasound Attenuation (BUA) and Speed of Sound (SOS). BUA, SOS, and proprietary combinations of the two (e.g., stiffness) characterize the mechanical properties of bone relating to elasticity, strength, and consequently fracture risk. QUS measurements at the heel have been found to be good predictors of spine fractures in the elderly when degenerative disease compromises the DXA spine scan. Other measurement sites, some under investigation, include the finger, tibia, iliac crest, vertebral arch and spinous processes, and femoral neck and greater trochanter.



**Fig. 39-31** Norland model pDEXA performs pDXA bone mineral analysis of the wrist.  
(Courtesy Norland, Inc., Ft. Atkinson, Wis.)



**Fig. 39-32** QUS of the heel uses either water as a coupling mechanism (*top*) or a dry system using a gel on the transducers (*bottom*).

(Courtesy GE-Lunar, Madison, Wis.)



## Summary

The main purpose of bone densitometry is to facilitate the diagnosis of osteoporosis by detecting low bone mass. Osteoporosis is now a treatable disease, and people concerned about their risk of this disease should consult their physician for a complete evaluation.

DXA scans of the hip and spine are the most widely performed techniques, but simpler, less expensive peripheral scans of the extremities are also used. Technologists performing these scans must be properly trained in scanner quality control, and patient scan positioning, acquisition, and analysis. This will ensure accurate and precise bone density results.

## Definition of Terms

**adult sprue** Disease characterized by hypersensitivity to gluten (wheat protein).

**anthropomorphic** Simulating human form.

**ALARA (As Low As Reasonably Achievable)** Principle of reducing patient radiation exposure and dose to lowest reasonable amounts.

**areal technique** See *projectional technique*.

**array-beam collimation** Dual energy x-ray absorptiometry system that uses a narrow "slit" x-ray collimator and a multi-element detector. The motion is in one direction only, which greatly reduces scan time and permits supine lateral spine scans. It introduces a slight geometric distortion at the outer edges, which necessitates careful centering of the object of interest.

**biochemical markers** Laboratory tests on blood and urine to detect levels of bone formation or resorption.

**body composition** Results from whole-body scans obtained by dual energy x-ray absorptiometry; reported as lean mass in grams, percent body fat, and bone mineral density of the total body and selected regions of interest.

**bone densitometry** Art and science of measuring the bone mineral content and density of specific anatomic sites or the whole body.

**bone mass** General term for the amount of mineral in a bone.

**bone mineral content (BMC)** Measure of bone mineral in the total area of a region of interest.

**bone mineral density (BMD)** Measure of bone mineral per unit area of a region of interest.

**bone remodeling** Process of bone resorption by osteoclasts, followed by bone formation by osteoblasts. The relative rates of resorption and formation determine whether bone mass increases, remains stable, or decreases.

**compare feature** Software feature of dual energy x-ray absorptiometry that replicates the size and placement of Regions of Interest from the reference scan to the follow-up scan.

**cortical bone** Dense, compact outer shell of all bones and the shafts of the long bones; supports weight, resists bending and twisting, and accounts for about 80% of the skeletal mass.

**discordance** Patient may have T-score indicating osteoporosis at one anatomical site but not at another site or by one modality but not by another.

**dual photon absorptiometry (DPA)** Obsolete method of measuring bone density at the hip or spine using a radioisotope source that produces two sources of photons; replaced by dual energy x-ray absorptiometry.

**dual energy x-ray absorptiometry (DXA)** Bone density measurement technique using an x-ray source separated into two energies. It has good accuracy and precision and can scan essentially any anatomic site, making it the most versatile of the bone density techniques.

**follow-up scans** Sequential scans, usually performed 18 to 24 months apart, to measure changes in bone density. Scans are best done on the same scanner or on a new scanner calibrated to the original scanner.

**fragility fractures** Nontraumatic fractures resulting from low bone mass, usually at the hip, spinal vertebrae, wrist, proximal humerus, or ribs.

**hip axis length (HAL)** Distance along the femoral neck axis from the base of the greater trochanter to the inner pelvic brim. An independent indicator of hip fracture risk.

**hyperparathyroidism** Disease caused by excessive secretion of parathyroid hormone (PTH) from one or more parathyroid glands resulting in excessive calcium in the blood. Effects cortical bone more than trabecular bone.

**kyphosis** Exaggerated outward curvature of the thoracic spine, also called dowager's hump.

**longitudinal quality control** Manufacturer-defined procedures performed on a regular basis to ensure that patients are scanned on properly functioning equipment with stable calibration. Scanning must be postponed until identified problems are corrected.

**mean** A statistic commonly called the average. The sum of the data values divided by the number of data values.

**morphometric x-ray absorptiometry (MXA)** Lateral scans of the thoracic and lumbar spine using single or dual x-ray absorptiometry to determine vertebral abnormalities or fractures from the shapes of the vertebrae.

**osteoblasts** Bone-building cells that fill the pits left by resorption with new bone.

**osteoclasts** Bone-destroying cells that break down and remove old bone, leaving pits.

**osteomalacia** Bone disorder characterized by variable amounts of uncalcified osteoid matrix.

**osteopenia** Reduction in bone mass, putting a person at increased risk of developing osteoporosis. By World Health Organization criteria, it is a bone mineral density or bone mineral content T-score between  $-1$  and  $-2.5$ .

**osteophytosis** Form of degenerative joint disease resulting from mechanical stress that increases the measured spinal bone mineral density.

**osteoporosis** Systemic skeletal disease characterized by low bone mass and deterioration of the bone structure, resulting in decreased mechanical competence of bone and an increase in susceptibility to fracture. By World Health Organization criteria, it is a bone mineral density or bone mineral content T-score of less than  $-2.5$ .

**overall risk of fragility fracture** Risk of suffering an unspecified fragility fracture. The risk for hip fracture specifically is best measured at the hip.

**peak bone mass** Maximum bone mass, usually achieved between 30 and 35 years of age. Population mean peak bone mass is used as a reference point for the T-score.

**pencil-beam collimation** Dual energy x-ray absorptiometry system using a circular pinhole x-ray collimator that produces a narrow x-ray stream, that is received by a single detector. Its motion is serpentine (or raster) across or along the length of the body. Modern systems have improved scan time and image quality. Off-centering of the object does not cause geometric distortion.

**percent coefficient of variation (%CV)** Statistic used to compare standard deviations from different data sets which may have different means. Also a measure of precision. Calculated as the SD divided by the mean, times 100. A smaller %CV indicates better precision.

**peripheral dual energy x-ray absorptiometry (pDXA)** Dual energy x-ray absorptiometry system designed to scan only the peripheral skeleton; smaller and simpler to operate than DXA scanners.

**peripheral quantitative computed tomography (pQCT)** Dedicated QCT system designed to measure bone density on the peripheral skeleton, usually the forearm.

**primary osteoporosis** Osteoporosis not caused by an underlying disease, classified as Type I or Type II.

**projectional (or areal) technique** Two-dimensional representation of a three-dimensional object.

**quantitative computed tomography (QCT)** System for quantitative CT measurements of bone density, allowing true measurement of volume and separation of trabecular and cortical bone; usually measured at spine or forearm, sometimes at hip.

**quantitative ultrasound (QUS)**

Quantitative measurement of bone properties related to mechanical competence using ultrasound. The results are reported in terms of broadband ultrasound attenuation (BUA), speed of sound (SOS), and a nonstandardized proprietary mathematical combination of the two, called the stiffness or Quantitative Ultrasound Index (QUI). It predicts overall or spine fracture risk without using ionizing radiation and is usually measured at the calcaneus.

**radiogrammetry** Older method of measuring bone loss by comparing the outer diameter and inner medullary diameter of small tubular bones, usually the finger phalanges, or metacarpals.

**radiographic absorptiometry (RA)**

Visual comparison of hand x-ray density with a known standard in the exposure field.

**reference population** Large, sex-matched, community-based population used to determine the average bone mineral density and standard deviation at each age; used as reference base for T-scores and Z-scores; may also be matched on ethnicity and weight.

**regions of interest (ROI)** Defined portion of bone density scans where the bone mineral density is calculated; may be placed manually or automatically by computer software.

**Shewhart Control Chart rules** Classic quality control rules based on comparing a data value to the mean and standard deviation of a set of similar values.

**scintillation counter** Counter employing a photomultiplier tube for the detection of radiation.

**secondary osteoporosis** Osteoporosis caused by an underlying disease.

**sieverts (Sv)** Measurement of effective radiation dose to a patient. Bone density doses are measured in microsieverts ( $\mu\text{Sv}$ ), which are 1 one millionth of one sievert.

**single photon absorptiometry (SPA)** Obsolete method of measuring bone density at the forearm using a single radioisotope source; replaced by single energy x-ray absorptiometry.

**single energy x-ray absorptiometry (SXA)** Bone density technique for the peripheral skeleton using a single energy x-ray source and an external medium, such as water, to correct for the effects of soft tissue attenuation. Scanners are smaller and simpler to operate than dual energy x-ray absorptiometry scanners.

**standard deviation (SD)** Measure of the variability of the data values about their mean value.

**standardized BMD (sBMD)** Result of converting bone mineral density values from one manufacturer to values that can be compared to other manufacturers by applying mathematical formulas. Reported in milligrams per centimeter squared ( $\text{mg}/\text{cm}^2$ ) to differentiate it from BMD.

**subtraction technique** Removal of the density attributable to soft tissue so the remaining density belongs only to bone.

**T-score** Number of standard deviations the individual's bone mineral density (BMD) is from the average BMD for sex-matched young normal peak bone mass.

**trabecular bone** Delicate, lattice-work structure within bones that adds strength without excessive weight; supports compressive loading at the spine, hip, and calcaneus and is also found in the ends of long bones such as the distal radius.

**type I osteoporosis** Primary osteoporosis related to postmenopausal status.

**type II osteoporosis** Primary osteoporosis related to aging.

**volumetric density** Bone mineral density calculated by dividing by the true three-dimensional volume.

**Ward's triangle** Region on the proximal femur lying on the border of the femoral neck and greater trochanter; has low bone mineral density.

**Z-score** Number of standard deviations the individual's bone mineral density (BMD) is from the average BMD for sex and age-matched reference group.

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## Resources for Information and Instruction

American College of Radiology: *ACR standard for the performance of adult dual or single x-ray absorptiometry (DXA/pDXA/SXA)*. Contact the Standards & Accreditation Department, American College of Radiology, 1891 Preston White Dr., Reston, VA 22091.

American Registry of Radiologic Technologists: *Provides a post-primary examination leading to a certificate of added qualifications in bone densitometry*. For details get the Examinee Handbook for Bone Densitometry. Contact the American Registry of Radiologic Technologists, 1255 Northland Dr., St. Paul, MN 55120-1155. Internet address: WWW.ARRT.ORG

American Society of Radiologic Technologists: *Approved elective curriculum in bone densitometry for radiography programs*. Contact the American Society of Radiologic Technologists, 15000 Central Ave. SE, Albuquerque, NM 87123. Internet address: WWW.ASRT.ORG

International Society for Clinical Densitometry: Certification courses, annual and regional meetings, continuing education, newsletter, Journal of Clinical Densitometry, and Web site with links. Contact International Society for Clinical Densitometry, 2025 M Street NW, Suite 800, Washington, DC 20036. Internet address: WWW.ISCD.ORG

National Osteoporosis Foundation: Excellent source of osteoporosis information and educational materials for technologists, physicians, and patients. Contact the National Osteoporosis Foundation, 1232 22nd St. NW, Washington, DC 20037-1292. Internet address: WWW.NOF.ORG

Scanner manufacturers: source for technologist instruction and answers to scanner specific application questions. Refer to the operator's manual for contact information.



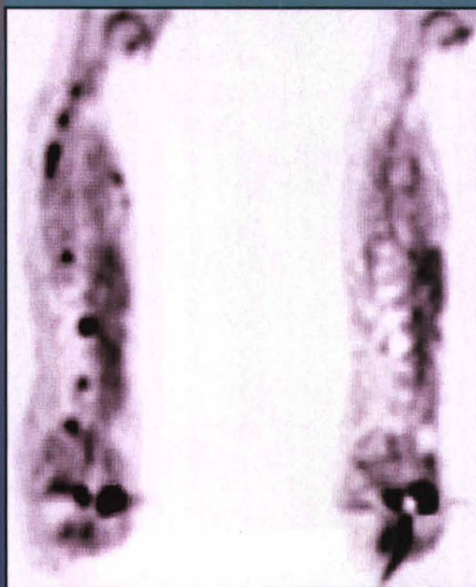


40

# POSITRON EMISSION TOMOGRAPHY

RICHARD D. HICHA

Whole-body PET images. *Left*, 18F-FDG sagittal image of patient with breast cancer metastasis. Numerous tumors (dark spots) are seen along the spine and sternum. *Right*, Image obtained after chemotherapy shows regression of the cancer.



## OUTLINE

Overview of positron emission tomography, 532  
Comparison with other modalities, 532  
Historical development, 534  
Principles and facilities, 535  
Clinical studies, 548  
Future studies, 550  
New frontiers, 551  
Summary, 552  
Definition of terms, 553

## Overview of Positron Emission Tomography

*Positron emission tomography (PET)\** is a noninvasive nuclear imaging technique that involves the administration of a radioactive molecule and subsequent imaging of the distribution and kinetics of the radioactive material as it moves into and out of tissues. PET imaging of the heart, brain, lungs, or other organs is possible if an appropriate radiopharmaceutical, also called a radiotracer or radiolabeled molecule, can be synthesized and administered to the patient.

Three important factors distinguish PET from all radiologic procedures and from other nuclear imaging procedures. First, the results of the data acquisition and analysis techniques yield an image related to a particular physiological parameter such as blood flow or metabolism. The ensuing image is aptly called a *functional* or *parametric image*. Second, the images are created by the simultaneous detection of a pair of *annihilation* radiation that results from *positron* decay (Fig. 40-1).

The third factor that distinguishes PET is the chemical and biological form of the radiopharmaceutical. The radiotracer is specifically chosen for its similarity to naturally occurring biochemical constituents of the human body. Because extremely small amounts of the radiopharmaceutical are administered, equilibrium conditions within the body are not altered. If, for instance, the radiopharmaceutical is a form of sugar, it will behave very much like the natural sugar utilized by the body. The kinetics or the movement of the radiotracer such as sugar within the body is followed by using the PET scanner to acquire many images that measure the distribution of the *radioactivity concentration* as a function of time. From this measurement the local tissue metabolism of the sugar may be deduced by converting a temporal sequence of images into a single parametric image that indicates tissue glucose utilization or more simply tissue metabolism.

\*Almost all italicized words on the succeeding pages are defined at the end of the chapter.

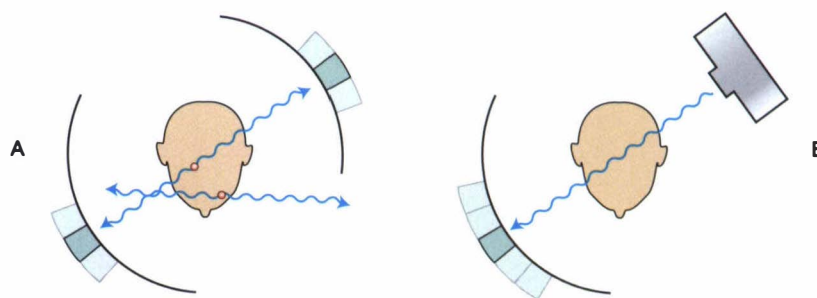
## Comparison with Other Modalities

PET is predominantly used to measure human cellular, organ, or system function. In other words, a parameter that characterizes a particular aspect of human physiology is determined from the measurement of the radioactivity emitted by a radiopharmaceutical in a given volume of tissue. In contrast, conventional radiography measures the structure, size, and position of organs or human anatomy by determining x-ray transmission through a given volume of tissue. X-ray attenuation by structures interposed between the x-ray source and the radiographic image receptor provides the contrast necessary to visualize an organ. Computed tomography (CT) creates cross-sectional images by computer reconstruction of multiple x-ray transmissions (see Chapter 33). The characteristics of PET and other imaging modalities are compared in Table 40-1.

*Radionuclides* used for conventional nuclear medicine (see Chapter 38) include  $^{99m}\text{Tc}$  (technetium),  $^{123}\text{I}$  (iodine),  $^{131}\text{I}$  (iodine),  $^{111}\text{In}$  (indium),  $^{201}\text{Tl}$  (thallium), and  $^{67}\text{Ga}$  (gallium). Labeled compounds with these high atomic weight radionuclides often do not mimic the physiological properties of natural substances because of their size, mass, and distinctly different chemical properties.

Thus compounds labeled with conventional nuclear medicine radionuclides are poor radioactive *analogs* for natural substances. Imaging studies with these agents are qualitative and emphasize nonbiochemical properties. The elements hydrogen, carbon, nitrogen, and oxygen are the predominant constituents of natural compounds found in the body. They have low atomic weight radioactive counterparts of  $^{11}\text{C}$  (carbon),  $^{13}\text{N}$  (nitrogen), and  $^{15}\text{O}$  (oxygen). Further, these positron-emitting radionuclides can directly replace their stable isotopes in substrates, metabolites, drugs, and other biologically active compounds without disrupting normal biochemical properties. In addition,  $^{18}\text{F}$  can replace hydrogen in many molecules, thereby providing an even greater assortment of biological analogs that are useful PET radiopharmaceuticals.

*Single photon emission computed tomography (SPECT)* employs nuclear imaging techniques to determine tissue function (see Chapter 38). Because SPECT employs collimators and lower energy photons, it is less sensitive (by  $10^1$  to  $10^5$ ) and less accurate than PET. In general, PET resolution is better than SPECT resolution by a factor of 2 to 10. PET easily accounts for photon loss through attenuation by performing a *transmission scan*. This is difficult to achieve and not routinely done with SPECT imaging; however, significant effort is now being directed towards designing SPECT instrumentation that couples a low output x-ray CT to the gamma camera for the collection of attenuation information. Software approaches are also being investigated that assign known attenuation coefficients for specific tissues to *segmented regions* of images for analytic attenuation correction of SPECT data.



**Fig. 40-1** **A**, PET relies on the simultaneous detection of a pair of annihilation radiations emitted from the body. **B**, In contrast, CT, depends on the detection of x-rays transmitted through the body.



The differences between the various imaging modalities can be highlighted using a study of brain blood flow as an example. Without an intact circulatory system, an IV-injected radiopharmaceutical cannot make its way into the brain for distribution throughout that organ's capillary network and ultimately diffusing into cells that are well perfused. For radiographic procedures such as CT, structures within the brain may well be intact but there may be impaired or limited blood flow to and through major vessels within the brain. Under these circumstances the CT scan may appear almost normal despite reduced blood flow to the brain. If the circulatory system at the level of the capillaries is not intact, a PET scan can be performed but no perfusion information will be obtained since the radioactive water used to measure blood flow will not be transported through the capillaries and diffuse into the brain cells.

The image-enhancing contrast agents used in many radiographic studies may cause a toxic reaction. The x-ray dose to the patient in these radiographic studies is greater than the radiation dose in nuclear imaging studies. The radiopharmaceuticals used in PET studies are similar to the body's own biochemical constituents and are administered in very small amounts. Biochemical compatibility of the tracers with the body minimizes the risks to the patient because the tracers are not toxic. Trace amounts minimize alteration of the body's *homeostasis*.

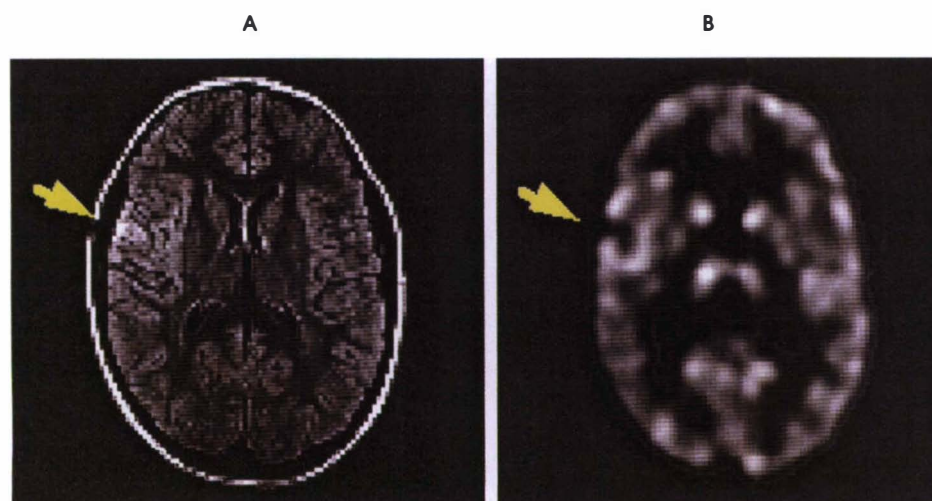
An imaging technique that augments both CT and PET is *magnetic resonance imaging (MRI)* (see Chapter 36). Images obtained with PET and MRI are shown in Fig. 40-2. MRI is used primarily to measure anatomy or morphology. Unlike CT, which derives its greatest image contrast from varying tissue densities (bone from soft tissue), MRI better differentiates tissues by their proton content and the degree to which the protons are bound in lattice structures. The tightly bound protons of bone make it virtually transparent to MRI.

**TABLE 40-1**

Comparison of imaging modalities

Modality information	Positron emission tomography	Single photon emission computer tomography	Magnetic resonance imaging	Computed tomography
Measures	Physiology	Physiology	Anatomy (physiology*)	Anatomy
Resolution	3 to 5 mm	8 to 10 mm	0.5 to 1 mm	1 to 1.5 mm
Technique	Positron annihilation	Gamma emission	Nuclear magnetic resonance	Absorption of x-rays
Harmful effects	Radiation exposure	Radiation exposure	None known	Radiation exposure
Use	Research and clinical	Clinical	Clinical (research*)	Clinical
Number of examinations per day	4 to 12	5 to 10	10 to 15	15 to 20

\*Secondary function.



**Fig. 40-2** Coregistered MRI and PET scans. The arrows indicate an abnormality on the anatomic image (**A**, MRI scan) and the functional image (**B**, PET scan). The  $^{18}\text{F}$ -FDG PET image depicts hypometabolic area of seizure focus (arrow) in a patient diagnosed with epilepsy.



Advances in the spectroscopic imaging of fluorine, phosphorus, and other elements now permit, to some degree, the determination of organ and cellular function of relatively large tissue volumes. The image *resolution* obtained from spectroscopic techniques is poorer than that obtained from conventional proton MRI imaging. It is now possible to measure blood flow in both large vessels and capillaries. Paramagnetic contrast agents, improved MRI instrumentation, absolute quantification, and spectroscopy remain the major areas of MRI research. Functional MRI (fMRI) is rapidly advancing and is now capable of acquiring simultaneous and coregistered regional brain blood flow information similar to that acquired with PET along with the usual excellent anatomical images. At this time functional MRI is still not completely validated against techniques of known accuracy.

It is important to note that CT, MRI, and other anatomic imaging modalities provide complementary information to PET. This imaging modality benefits from *image coregistration* with CT and MRI by pinpointing physiologic function from precise anatomic locations. Greater emphasis is being placed on multimodality image coregistration between PET, CT, SPECT, and MRI for brain research and for tumor localization throughout the body. Significant effort is underway to develop multimodality imaging instruments such as PET/CT devices as discussed in the New Frontiers section and shown in Fig. 40-22. PET still remains unique in its ability to measure *in vivo* (i.e., within a living organism) physiology because its results are quantitative, rapidly repeatable, and validated against those of accurate but much more invasive techniques.

## Historical Development

The use of positron-emitting radiopharmaceuticals for medical purposes was first conceived in the early 1930s by E.O. Lawrence, the inventor of the *cyclotron*. Simple compounds with positron-emitting radionuclides were synthesized, and Geiger counters were used to qualitatively measure the relative uptake of these compounds in various parts of the body.

It was not until more suitable *scintillators*, such as sodium iodide (NaI), and more sophisticated nuclear counting electronics became available that positron coincidence localization was possible. F.W. Wrenn demonstrated the use of positron-emitting radioisotopes for the localization of brain tumors in 1951. G.L. Brownell further developed instrumentation for similar studies. The next major advance came in 1967, when G. Hounsfield demonstrated the clinical use of CT. The mathematics of PET image *reconstruction* is very similar to those used for CT reconstruction techniques. Instead of x-rays from a point source traversing the body and being detected by a single or multi-detector as in CT, PET imaging uses two opposing detectors to simultaneously count pairs of 0.511-MeV photons that originate from a single positron-electron annihilation event.

From 1967 through 1974, significant developments occurred in computer technology, scintillator materials, and *photo-multiplier tube (PMT)* design. In 1975 the first closed-ring transverse positron tomograph was built for PET imaging by M.M. Ter-Pogossian and M.E. Phelps.

Developments now continue on two fronts which have accelerated the use of PET. First, scientists are approaching the theoretical limits (1 to 2 mm) of PET scanner resolution by employing smaller, more efficient scintillators and PMTs. Microprocessors tune and adjust the entire ring of *detectors* that surround the patient. Each ring in the PET tomograph may contain as many as 1000 detectors. Further, the tomograph may be composed of 30 to 60 rings of detectors. The second major area of development is in the design of new radiopharmaceuticals. Agents are being developed to measure blood flow, metabolism, protein synthesis, lipid content, receptor binding, and many other physiologic parameters and processes.

During the mid 1980s, PET was used predominantly as a research tool; however, by the early 1990s, clinical PET centers had been established and PET was routinely used for diagnostic procedures on the brain, heart, and tumors. The middle to late 1990s saw the development of three-dimensional PET systems that eliminated the use of interdetector *septa*. This allowed the injected dose of the radiopharmaceutical to be reduced by approximately sixfold to tenfold. New image reconstruction methods have been developed to better characterize the distribution of annihilation photons from these 3D systems. Throughout 2000 and 2001, major PET instrument manufacturers have developed combined PET and CT systems that can simultaneously acquire PET functional images and CT anatomical images. Both modalities are coregistered or exactly matched in size and position. Significant benefits are expected for diagnosing metastatic disease since precise localization of tumor size and tumor function can be determined. Rapid enhancements and developments are anticipated throughout the next several years with this technology.

## Principles and Facilities

The following sections discuss the major concepts of *positrons*, PET and the equipment used in this type of imaging. PET is a multidisciplinary technique that involves four major processes: radionuclide production, radiopharmaceutical production, data acquisition (PET scanner or tomograph), and a combination of image-reconstruction and image-processing to create images that depict tissue function.

### BOX 40-1

#### Positron characteristics

Definition: positively charged electron  
 Origin: neutron-deficient nuclei  
 Production: accelerators  
 Nuclide decay:  $p = n + \beta^+ \text{ neutrino}$   
 Positron decay: annihilation to two 0.511-MeV photons  
 Number: about 240 known  
 Range: proportional to kinetic energy of  $\beta^+$   
 Routine PET nuclides:  $^{11}\text{C}$ ,  $^{13}\text{N}$ ,  $^{15}\text{O}$ ,  $^{18}\text{F}$ ,  $^{68}\text{Ga}$ ,  $^{82}\text{Rb}$

## POSITRONS

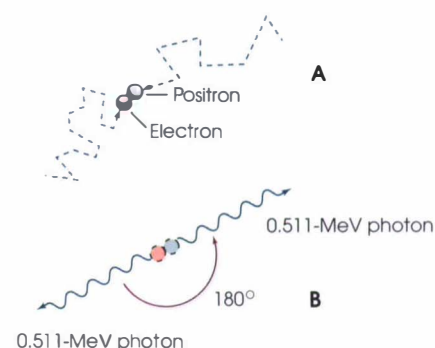
Living organisms are composed primarily of compounds that contain the elements hydrogen, carbon, nitrogen, and oxygen. In PET, radiotracers are made by synthesizing compounds with radioactive isotopes of these elements. Chemically the radioactive isotope is indistinguishable from its equivalent stable isotope. Neutron-rich (more neutrons than protons) radionuclides emit electrons or beta particles. The effective range or distance traveled for a 1-MeV beta particle ( $\beta^-$ ) in human tissue is only 4 mm. These *radionuclides* typically do not emit other types of radiation that can be easily measured externally with counters or scintillation detectors. The only radioisotopes of these elements that can be detected outside the body are positron-emitting nuclides. The stable and radioactive nuclides of several elements are depicted in Fig. 40-3.

Positron-emitting radionuclides have a neutron-deficient nucleus (i.e., the *nucleus* contains more protons than neutrons and thus is also called a *proton-rich nucleus*). Positrons ( $\beta^+$ ) are identical in mass to electrons, but they possess positive instead of negative charge. The characteristics of positrons are given in Box 40-1. Positron decay occurs in unstable radioisotopes only if the nucleus possesses excess energy greater than the energy equivalent of two electron rest masses, or a total of 1.022 MeV. Positrons are emitted from the nucleus with high velocity and kinetic energy. They are rapidly slowed by interactions in the surrounding tissues until all of the positron kinetic energy is lost. At this point the positron combines momentarily with an electron. The combination of particles will totally annihilate or disintegrate, and the combined positron-electron mass of 1.022 MeV is transformed into two equal-energy photons of 0.511 MeV, which are emitted at 180 degrees from each other (Fig. 40-4).

			F 17 64.5 s	F 18 1.83 h	F 19 100%	F 20 11 s
	O 14 70.6 s	O 15 122.2 s	O 16 99.76%	O 17 0.04%	O 18 0.2%	O 19 26.9 s
	N 13 9.97 m	N 14 99.63%	N 15 0.37%	N 16 7.13 s		
C 11 20.3 m	C 12 98.9%	C 13 1.1%	C 14 5730 y	C 15 2.45 s		

**Fig. 40-3** Excerpt from *The Chart of the Nuclides* showing the stable elements (shaded boxes), positron emitters (to the left of the stable elements), and beta emitters (to the right of the stable elements). Isotopes farther from their stable counterparts have very short half-lives. The most commonly used PET nuclides are  $^{11}\text{C}$ ,  $^{13}\text{N}$ ,  $^{15}\text{O}$ , and  $^{18}\text{F}$ .

(From Walker FW et al: *The Chart of the Nuclides*, ed 13, San Jose, Calif. 1984, General Electric Company.)



**Fig. 40-4** Neutron-deficient nuclei decay by positron emission. A positron is ejected from the nucleus and loses kinetic energy by scattering (erratic line on **A**) until it comes to rest and interacts with a free electron. Two photons of 0.511 MeV ( $E=m_0c^2$ ) result from the positron and electron annihilation (wavy line in **B**).

These annihilation photons behave like *gamma rays*, have sufficient energy to traverse body tissues with only modest attenuation, and can be detected externally. Because two identical or isoenergetic photons are emitted at exactly 180 degrees from each other, the nearly simultaneous detection of both photons defines a line that passes through the body. The line is located precisely between the two scintillators that detected the photons. A simplified block diagram for a single coincidence circuit is shown in Fig. 40-5. The creation of images from coincidence detection is discussed in the Data Acquisition section of this chapter.

The positron annihilation photons from the positron-emitting radionuclides of carbon, nitrogen, and oxygen can be used for external detection. Table 40-2 depicts the positron ranges for three positron energies in tissue, air, and lead. Hydrogen has no positron-emitting radioisotope; however,  $^{18}\text{F}$  is a positron ( $\beta^+$ ) emitter that is used as a hydrogen substitute in many compounds. This substitution of radioactive fluorine for hydrogen is successfully accomplished because of its small size and strong bond with carbon.

## RADIONUCLIDE PRODUCTION

Positron-emitting radionuclides are produced when a *nuclear particle accelerator* bombards appropriate nonradioactive *target* atoms with nuclei accelerated to high energies. The high energies are necessary to overcome the electrostatic and nuclear forces of the target nuclei so that a nuclear reaction can take place. An example is the production of  $^{15}\text{O}$ . *Deuterons*, or heavy hydrogen ions (the deuterium atom is stripped of its electron leaving only the nucleus with one proton and one neutron), are accelerated to approximately 7 MeV. The target material is stable nitrogen gas in the form of an  $\text{N}_2$  molecule. The resultant nuclear reaction yields a neutron and an  $^{15}\text{O}$  atom, which can be written in the following form:  $^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$ . The  $^{15}\text{O}$  atom quickly associates with a stable  $^{16}\text{O}$  atom that has been intentionally added to the target gas to produce a radioactive  $^{15}\text{O}$ - $^{16}\text{O}$  molecule in the form of  $\text{O}_2$ .

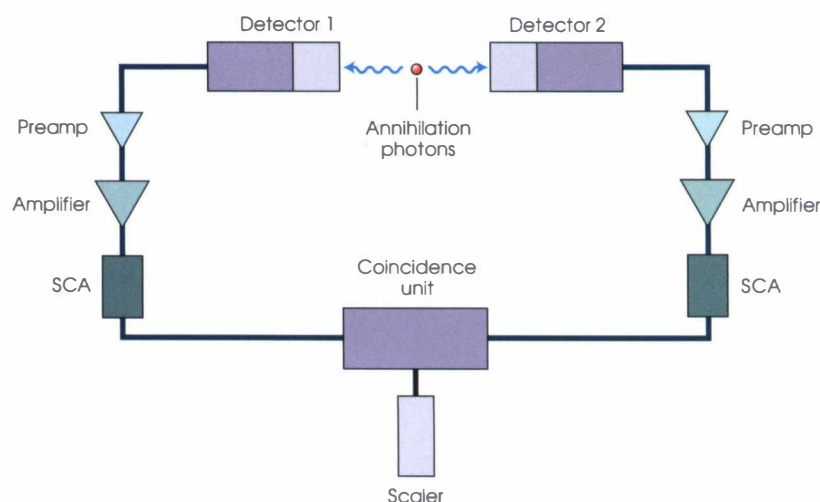
**TABLE 40-2**

Range (R) of positrons ( $\beta^+$ ) in centimeters

E(MeV)*	R <sub>tissue</sub>	R <sub>air</sub>	R <sub>lead</sub>
0.5	0.15	127	0.01
1.0	0.38	279	0.03
1.5	0.64	508	0.05

From *Radiological Health Handbook*, U.S. Dept. of Health, Education, and Welfare, Rockville, Md, 1970, Bureau of Radiological Health.

\*The average positron energy is approximately one third the maximum energy (see Fig. 40-7).

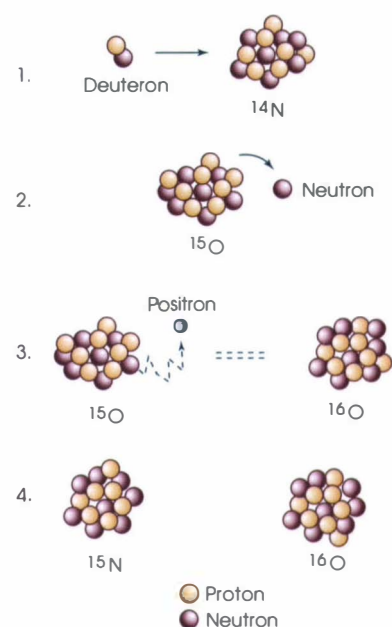


**Fig. 40-5** Simplified coincidence electronics for one pair of detectors in a PET tomograph.



Statistically, it is very unlikely that two  $^{15}\text{O}$  radionuclides will combine to form a doubly radioactive  $^{15}\text{O}$ - $^{15}\text{O}$  molecule because the total number of  $^{15}\text{O}$  atoms created in the target is small compared with the number of intentionally added  $^{16}\text{O}$  atoms. The unstable or radioactive  $^{15}\text{O}$  atom when it decays emits a positron. This radioactive decay process transforms a proton into a neutron. Hence upon decay the  $^{15}\text{O}$  atom becomes a stable  $^{15}\text{N}$  atom and the  $\text{O}_2$  molecule breaks apart. This process is shown in Fig. 40-6, and the decay schemes for the four routinely produced PET radionuclides are depicted in Fig. 40-7. The common reactions used for the production of positron-emitting forms of carbon, nitrogen, oxygen, and fluorine are given in Table 40-3.

Because of the very short half-lives of the routinely used positron-emitting nuclides of oxygen, nitrogen and carbon, nearby access to a nuclear particle accelerator is necessary to produce sufficient quantities of these radioactive materials. The most common device to achieve nuclide production within reasonable space (250 ft<sup>2</sup> [223 m<sup>2</sup>]) and energy (150 kW) constraints is a compact medical cyclotron. This device is specifically designed for the following: (1) simple operation by the technologist staff, (2) reliable and routine operation with minimal downtime, and (3) computer-controlled automatic operation to reduce overall staffing needs.

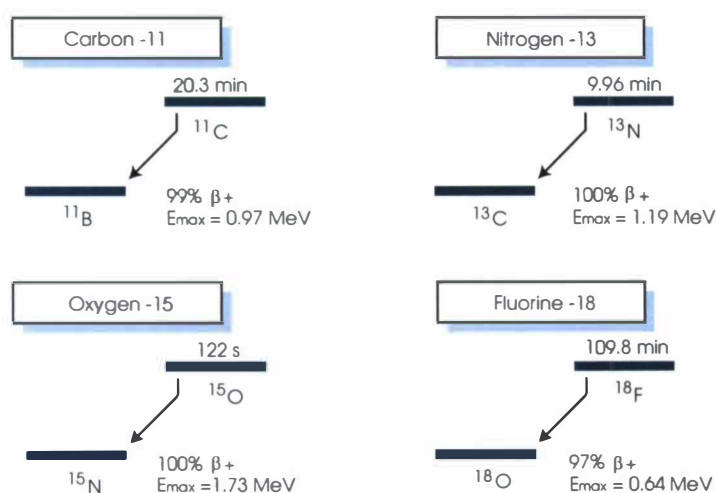


**Fig. 40-6** Typical radionuclide production sequence. The  $^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$  reaction is used for making  $^{15}\text{O}$ - $^{16}\text{O}$  molecules. 1. A deuteron ion is accelerated to high energy (7 MeV) by a cyclotron and impinges on a stable  $^{14}\text{N}$  nucleus. 2. As a result of the nuclear reaction, a neutron is emitted, leaving a radioactive nucleus of  $^{15}\text{O}$ . 3. The  $^{15}\text{O}$  atom quickly associates with an  $^{16}\text{O}$  atom to form an  $\text{O}_2$  molecule. Sometime later the unstable  $^{15}\text{O}$  atom emits a positron. 4. As a result of positron decay (i.e., positron exits nucleus), the  $^{15}\text{O}$  atom is transformed into a stable  $^{15}\text{N}$  atom and the  $\text{O}_2$  molecule breaks apart.

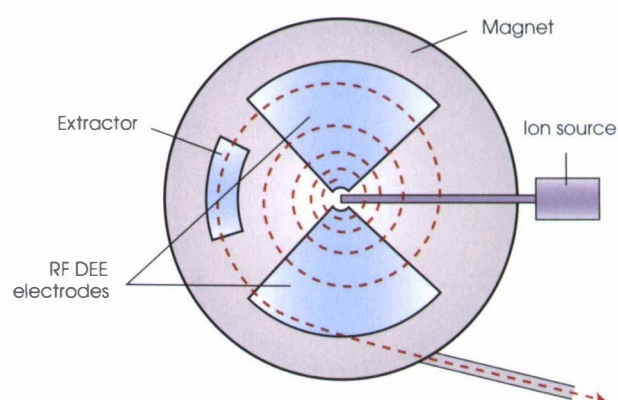
**TABLE 40-3**

Most common production reactions and target materials for the typical nuclides used in positron emission tomography

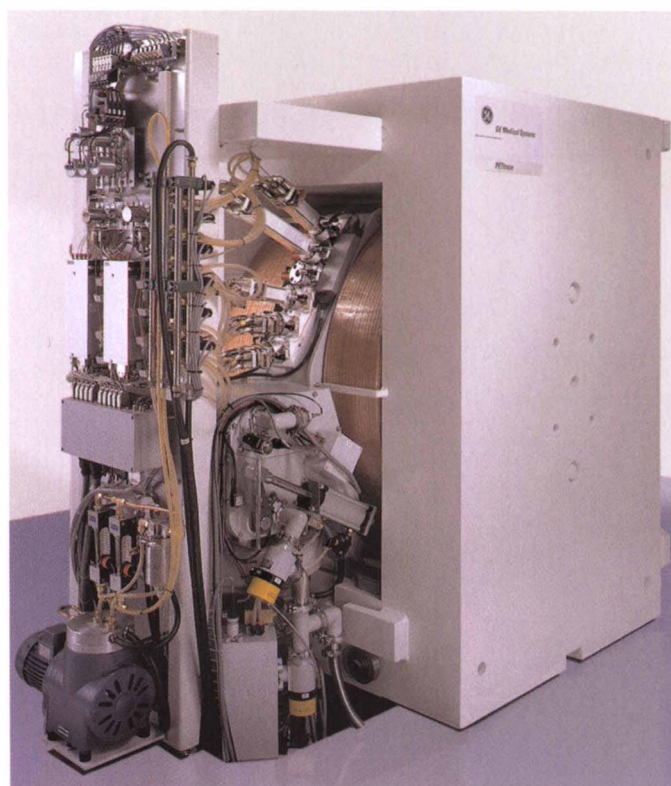
Nuclide	Half-life	Reaction(s)		Target material
		Proton	Deuteron	
$^{11}\text{C}$	20.4 min	$^{14}\text{N}(\text{p},\alpha)^{11}\text{C}$		$\text{N}_2$ (gas)
$^{13}\text{N}$	9.97 min	$^{16}\text{O}(\text{p},\alpha)^{13}\text{N}$		$\text{H}_2\text{O}$ (liquid)
$^{15}\text{O}$	2.03 min	$^{15}\text{N}(\text{p},\text{n})^{15}\text{O}$	$^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$	$\text{N}_2 + 1\% \text{O}_2$ (gas)
$^{18}\text{F}$	109.8 min	$^{18}\text{O}(\text{p},\text{n})^{18}\text{F}$	$^{20}\text{Ne}(\text{d},\alpha)^{18}\text{F}$	95% $^{18}\text{O} - \text{H}_2\text{O}$ (liquid) Ne + 0.1% $\text{F}_2$ (gas)



**Fig. 40-7** Decay schemes for  $^{11}\text{C}$ ,  $^{13}\text{N}$ ,  $^{15}\text{O}$ , and  $^{18}\text{F}$ . Each positron emitter decays to a stable nuclide by ejecting a positron from the nucleus.  $E_{\text{max}}$  represents the maximum energy of the emitted positron. Electron capture is a competitive process with positron decay; hence positron decay is not always 100%.



**Fig. 40-8** Cyclotron schematic. The dashed line indicates the path of accelerated particles for a positive-ion cyclotron. Ions originate at the ion source, are constrained to circular paths by the magnetic field, are accelerated to higher energy and thus larger orbits by the RF applied to the DEE electrodes, and are finally directed toward the target by the extractor. For a negative-ion cyclotron with the magnetic field oriented in the same direction as the positive-ion cyclotron, the ions to be accelerated orbit clockwise rather than counterclockwise as shown in the figure.



**Fig. 40-9** Compact cyclotron (2.2 m high by 1.5 m wide by 1.5 m deep) used for routine production of PET isotopes. The cyclotron can be located in a concrete vault, or it can be self-shielded. Particles are accelerated in vertical orbits and impinge on targets located near the top center of the machine. This is an example of a negative-ion cyclotron.

(Courtesy GE Medical Systems, Milwaukee, Wis.)

New linear accelerators have been developed that can also produce significant quantities of PET nuclides, but cyclotrons remain the most ubiquitous particle accelerator for PET applications.

A cyclotron consists of four major parts: the ion source, the magnet, the radiofrequency (RF) high-voltage acceleration system, and the extraction system (Fig. 40-8).

The ion source is used to create ions for acceleration from simple stable gases (e.g., protons from ionized hydrogen gas or deuterons from ionized deuterium gas). These ions are positive ions if their electrons have been stripped away and negative ions if an extra electron has been added. The ions are extracted from the ion source and accelerated in a spiral trajectory composed of ever increasing somewhat circular orbits toward the outer rim of the cyclotron magnet. The magnet systems are used to constrain the charged particles or ions to move in nearly circular orbits. As might be expected, particles with higher energy move with greater velocity and therefore travel in orbits of greater radii than particles with lower energy.

Fig. 40-9 shows a typical cyclotron used for radionuclide production. The cyclotron must be located in a thick concrete vault (a room with 5- to 6-foot [1.5- to 1.8-m] thick walls and ceiling), or it must have shielding material placed directly on all cyclotron exterior surfaces (self-shielded cyclotron) to reduce the radiation levels to safe values when the cyclotron is in operation (less than 2 mR/hr on contact with shield for areas not accessible to the general public).

Ions are accelerated by traversing the electric field gradient between the copper “dee” electrodes, whose shape somewhat resembles the capital letter D. The electric field gradient is created by charging the dees to a high voltage (30 to 50 kV), much as a large capacitor is charged. A positive ion is repelled by the positive polarity of one dee and attracted towards the negative polarity of the other dee. In this process, the ion gains kinetic energy and its velocity increases by moving from one dee to the next. Once an ion is enveloped by the conducting dee structure, it no longer experiences electrostatic forces and is constrained to move in a circular orbit toward the opposite dee by the magnetic field (1.4 to 1.8 tesla). During this time the polarity of the dees automatically reverses. The alternating voltage cycle occurs at radio frequencies of 10 to 30 MHz. Therefore, each time the ion traverses the gap between the two dees, it is accelerated by the respective attractive and repulsive electrostatic forces. It gains approximately twice the voltage difference between the two dees for every orbit or complete circular path. If the dee-to-dee voltage is 30 kV, a proton gains 60 keV of energy per orbit and undergoes approximately 280 to 300 orbits to achieve the maximum output energy, which is 17 MeV for the cyclotron shown in Fig. 40-9. During this time the ion increases its orbital radius from approximately 2 cm at the center of the cyclotron to near 35 cm the outer edge of the main magnetic field by following an increasingly larger spiral path.

For positive-ion cyclotrons, a high-voltage electrostatic deflector operating at 20 to 50 kV is used to nudge positive ions from the edge of the magnetic field to a point where they can be extracted from the cyclotron. For negative-ion cyclotrons, negative ions (proton plus 2 electrons or deuteron plus 2 electrons) are extracted by removing the added electrons by passing the ions through an extremely thin carbon foil (0.0025 mm thick). Because the overall charge on the ions was once negative ( $H^-$ ) and is now positive ( $H^+$ ), the ions circulate in the opposite direction under the influence of the constant magnetic field produced by the large electromagnet of the cyclotron. The extraction system permits negative ions to be more easily removed from the cyclotron than positive ions. Furthermore, the electrostatic deflector used in positive ion systems becomes extremely radioactive under normal use, whereas the carbon foil extraction system found in negative ion systems does not. This difference is considered a significant advantage in favor of the negative-ion accelerator. Nearly all new cyclotrons that are being designed and installed utilize negative ion systems.

The ion source emits ions with every cycle of the RF voltage applied to the dees regardless of ion polarity. Therefore ions arrive at the extraction system in packets synchronized with the RF. These packets, or beams of particles (10 to 50  $\mu A$  of protons or deuterons), are focused and directed toward the target material for the production of positron-emitting radioisotopes. The radioisotopes produced in the target may be solid, liquid, or gaseous, and they may be created continuously or in batches.

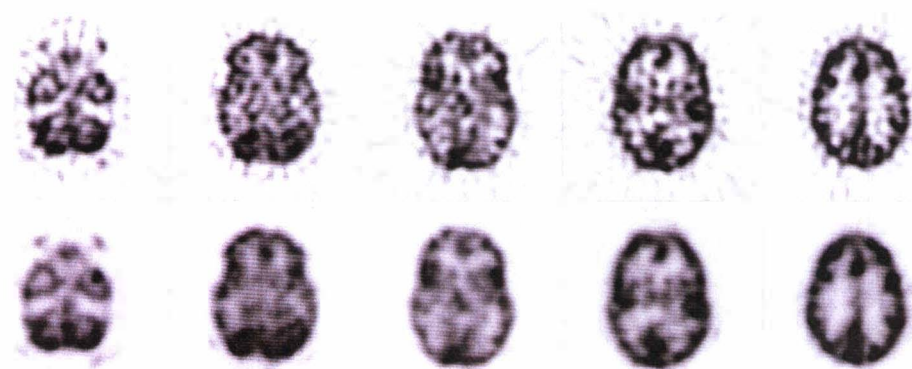
Proton-only cyclotrons produce nuclides by the reactions listed in Table 40-3 (see proton column). For cyclotrons that can produce both protons and deuterons, all of the reactions in Table 40-3 are possible; however, the  $^{14}N(d,n)^{15}O$  deuteron reaction is used primarily to produce  $^{15}O$ , whereas all other nuclides are typically produced with protons.



### RADIOPHARMACEUTICAL PRODUCTION

Radiopharmaceuticals are synthesized from radionuclides derived from the target material. These agents may be very simple, like the  $^{15}\text{O}$ - $^{16}\text{O}$  molecules described earlier, or they may be very complex. Regardless of the chemical complexity of the radioactive molecule, all radiopharmaceuticals must be synthesized very rapidly. This entails specialized techniques not only to create the labeled substance but also to verify the purity (chemical, radiochemical, and radionuclidic) of the radiotracer.

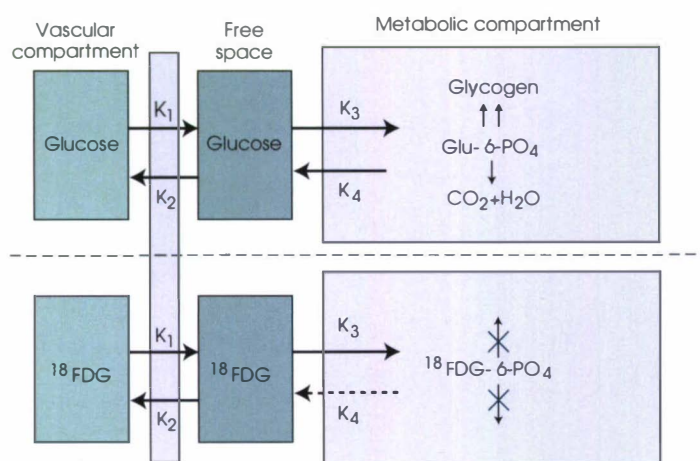
Two important radiopharmaceuticals are presently used in many PET studies. The simplest is  $^{15}\text{O}$  water ( $^{15}\text{O}$ - $\text{H}_2\text{O}$ ), which is produced continuously from the  $^{14}\text{N}(\text{d},\text{n})^{15}\text{O}$  nuclear reaction or in batches from the  $^{15}\text{N}(\text{p},\text{n})^{15}\text{O}$  nuclear reaction. As previously discussed, the radioactive oxygen quickly combines with a stable  $^{16}\text{O}$  atom, which has been added to the stable  $\text{N}_2$  target gas, to form an oxygen molecule ( $\text{O}_2$ ). The  $^{15}\text{O}$ - $^{16}\text{O}$  molecule is reduced over a platinum catalyst with small amounts of stable  $\text{H}_2$  and  $\text{N}_2$  gas. Radioactive water vapor is produced and collected in sterile saline for injection. A typical bolus injection of  $^{15}\text{O}$ - $\text{H}_2\text{O}$  is approximately 30 to 50 mCi in a volume of 1 to 2 ml of saline for use in a PET scanner that acquires data in 2D and approximately 3 to 8 mCi in the same volume of saline for a PET tomograph of the newer 3D design. A dose of radioactive water can be prepared every 2 to 5 minutes. Radioactive  $^{15}\text{O}$ - $\text{H}_2\text{O}$  is used primarily for the determination of *local cerebral blood flow (LCBF)*. PET LCBF images from one subject using two different techniques are shown in Fig. 40-10. Blood flow to tumor, heart, kidney, or other tissues can also be measured using  $^{15}\text{O}$ - $\text{H}_2\text{O}$ .



**Fig. 40-10** PET LCBF images. The images in the top row were created using a standard filtered backprojection reconstruction technique. An iterative reconstructive method was used to create the images in the bottom row from the same raw data that are used for the upper images. In all images, dark areas correspond to high brain blood flow. There is about an 8-mm separation between each brain slice within a row.

The most widely used PET radiopharmaceutical for clinical PET imaging is more complex than labeled water and employs  $^{18}\text{F}$ -labeled fluoride ions ( $\text{F}^-$ ) to form a sugar analog called [ $^{18}\text{F}$ ]-2-fluoro-2-deoxy-D-glucose, or  $^{18}\text{F}$ -FDG. This agent is used to determine the *local metabolic rate of glucose utilization (LMRG)* in tumor, brain, heart, or other tissues that use glucose as a metabolic substrate. For example, the glucose obtained from food is metabolized by the brain to provide the adenosine triphosphate necessary for maintaining the membrane potential of neurons within the brain. The metabolism of glucose is proportional to the neural activity of the brain and thus brain metabolism. Radioactive  $^{18}\text{F}$ -FDG and glucose enter the same biochemical pathways in the brain. However, unlike glucose,  $^{18}\text{F}$ -FDG cannot be completely metabolized in the brain because its metabolism is blocked at the level of fluoro-deoxyglucose-6-phosphate ([ $^{18}\text{F}$ ]-FDG-6- $\text{PO}_4$ ). Because  $^{18}\text{F}$ -FDG follows the glucose pathway into the brain, the concentration of [ $^{18}\text{F}$ ]-FDG-6- $\text{PO}_4$  within the brain cells is proportional to brain tissue metabolism. These pathways for glucose and  $^{18}\text{F}$ -FDG are shown schematically in Fig. 40-11.

$^{18}\text{F}$ -FDG is synthesized by displacing the triflate-leaving group of 1,3,4,6-tetra-O-acetyl-2-O-trifluoromethanesulfonyl-E1-D-mannopyranose with anhydrous  $^{18}\text{F}$ -fluoride, obtained from drying  $^{18}\text{F}$ -fluoride ions generated by proton bombardment of stable  $^{18}\text{O}$ - $\text{H}_2\text{O}$  (see Table 40-4). The intermediate is deacetylated by acid hydrolysis and purified chromatographically to give [ $^{18}\text{F}$ ]-2-fluoro-2-deoxy-D-glucose, or  $^{18}\text{F}$ -FDG. Injected doses range from 5 to 20 mCi with a standard dose being 10 mCi. FDG is dissolved in a few milliliters of isotonic saline and is administered intravenously. The total time for FDG production, which includes target irradiation (1 hour to 90 minutes), radiochemical synthesis (30 minutes to 1 hour), and purity certification (15 minutes), is approximately 2 to 3 hours, depending on the exact synthesis method used.

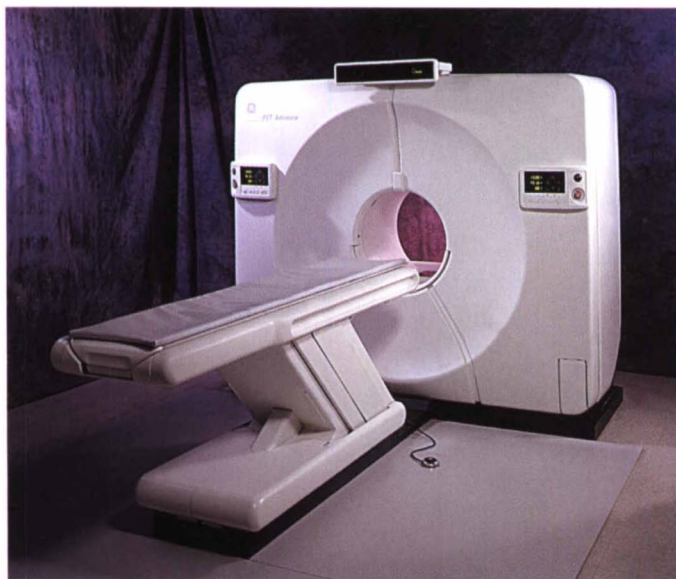


**Fig. 40-11** Glucose compartmental model (above the *dashed line*) compared with the  $^{18}\text{F}$ -FDG model (below the *dashed line*). Note that  $^{18}\text{F}$ -FDG does not go to complete storage (glycogen) or metabolism ( $\text{CO}_2 + \text{H}_2\text{O}$ ) as does glucose. The constants ( $K$ ) refer to reaction rates for moving substances from one compartment to another. Dashed arrow refers to extremely small  $K$  value that can usually be neglected.

### DATA ACQUISITION

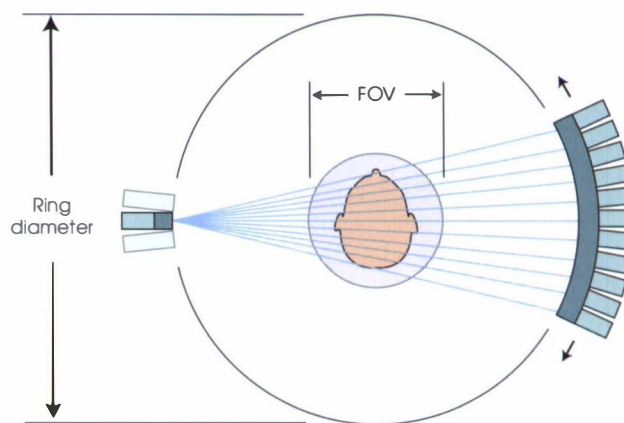
The positron-electron annihilation photons are detected and counted with a PET scanner or tomograph (Fig. 40-12). For neurologic PET scanners the distance between detector faces is approximately 70 cm (28 inches). This distance is increased from 90 to 100 cm (36 to 39 inches) for whole-body scanners. The radial field of view (FOV) or the imaging dimension parallel to the detector rings for these scanners is approximately 24 cm (10 inches) and 55 cm (22 inches), respectively (Fig. 40-13). The z-axis or dimension perpendicular to the detector rings is 15 to 50 cm (6 to 20 inches). Typical new scanners have 800 to 1000 detectors per ring. A detector module consists of *BGO scintillators* organized into a matrix ( $6 \times 6$ ,  $7 \times 8$ , or  $8 \times 8$ ) of small rectangular boxes (3 to 6 mm long, 3 to 6 mm wide, and 10 to 30 mm deep), which are coupled to photomultiplier tubes (PMT). A new scintillator, lutetium orthosilicate ( $\text{Lu}_2\text{SiO}_5:\text{Ce}$ ), also known as LSO, has a higher light output (approximately four times that of BGO) and faster photofluorescent decay (approximately 7.5 times that of BGO). Scintillator dimensions are being reduced to improve resolution. LSO and BGO crystal sizes are approaching 1 to 2 mm long by 1 to 2 mm wide and 10 to 30 mm deep.

Individual photomultiplier tubes are no longer mated to single scintillator crystals, as was used in the first PET scanners. Current PMTs are arranged in an overlapping fashion similar to NaI crystals and photomultiplier tubes in conventional gamma cameras. Early scanners had only a single ring of detectors. Current tomographs are constructed of 18 to 24 rings with some experimental units having 50 rings of detectors. Not only are coincidence counts collected for detector pairs within each ring (direct-plane information), but data are also collected between adjacent rings (cross-plane information) as shown in Fig. 40-14. Therefore 35 to 47 tomographic slices ( $2 \times \text{number of rings} - 1$ ) can be acquired simultaneously for 18- to 24-ring tomographs, which have a total of 10,000 to 20,000 detectors (BGO or LSO crystals).



**Fig. 40-12** Typical whole-body PET scanner. The bed is capable of moving in and out of the scanner to measure the distribution of PET radiopharmaceuticals throughout the body, and it adjusts to a very low position for easy patient access. Sophisticated computer workstations are required to view and analyze data.

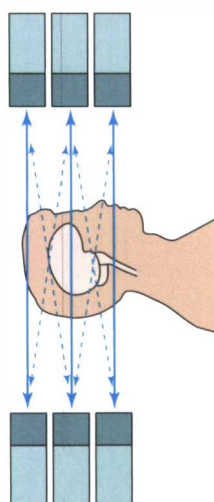
(Courtesy GE Medical Systems, Milwaukee, Wis.)



**Fig. 40-13** Detector arrangement in neurologic PET ring (head-only scanner). Rays from opposed detector pairs (lines between detectors) depict possible coincidence events. The useful field of view (FOV) is delineated by the central circle.



The concept of PET scanner resolution can be explained using a bicycle wheel as an example. In the case of PET, lines drawn between detectors or *rays* correspond to the bicycle spokes. The highest density of spokes is located at the hub. At the rim of the wheel, the density of spokes is reduced. The same is true for the density of rays between detectors. That is why the selected radial imaging FOV for these scanners is approximately the middle third of the distance from one detector face to the opposite detector face. Adequate ray density for the best resolution for image reconstruction is achieved only within this FOV. The same holds for the axial or longitudinal dimension (z-axis). Approximately two thirds of the axial FOV contains sufficient ray sampling. By acquiring several axial FOVs which is achieved by moving the bed through the PET scanner, the amount of data under sampled is significantly reduced. Each axial FOV is overlapped with the next. Therefore sufficient axial sampling is achieved for all but the first and last bed position.



**Fig. 40-14** Side-view schematic of a small portion of a multiring (three-ring) PET tomograph. The *darker green squares* indicate the scintillator-matrix, which is attached to multiple-photocathode PMTs. *Solid lines* indicate the direct planes, and *dashed lines* depict the cross planes. The X determined by the pair of cross planes forms a data plane located between direct planes. Improvements in PET scanner instrumentation not only permit cross-plane information between adjacent rings to be acquired but also allow for expansion to the second, third, fourth, and fifth near neighbor rings. This significantly enhances overall scanner sensitivity.

The resolution within the image plane for PET scanners is between 3 and 5 mm full width at half maximum (FWHM). Thus an image of a point source of radioactivity appears to be 3 to 5 mm wide at one half the maximum intensity of the source image. The theoretical limit of resolution for PET tomographs is 1 to 2 mm FWHM and depends on the finite range of the positron in tissue for the particular radionuclide used. However, animal PET scanners have achieved this resolution; hence, the average positron range may not be a lower limit to better PET resolution. The resolution between tomographic planes or slices (i.e., along the z axis, which is the axis parallel to the PET scanner couch) is between 3 and 4 mm FWHM.

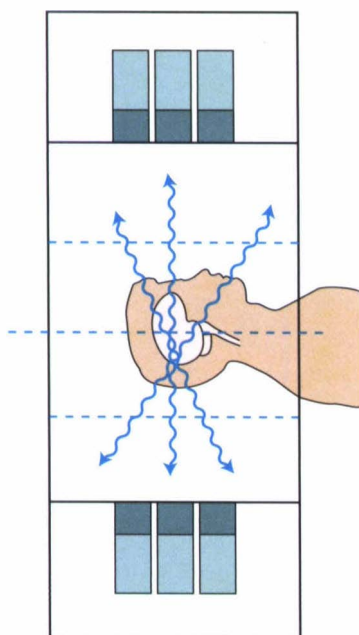
Further improvements in image resolution require that the number of rays between detectors be increased. This implies that the number of detectors in the tomograph must be increased. Some devices now being constructed will have more than 1000 detectors per ring. Of course, as the number of detectors in the tomograph increases, so does the complexity of acquiring and cataloging each annihilation event. The electronics systems, wiring, and heat loads generated from the associated electronics also increase. Previously, methods for improving resolution employed rotation of the detector array with respect to the patient. This rotation of the detectors achieved an increase in the number of rays used for image reconstruction. However, the complexity of detector rotation and the additional costs to engineer these systems limited the usefulness of this technique. Therefore increasing the number of detectors in the ring is the most effective way of improving image resolution, and it does so without detector motion.

Not all photons emitted from the patient can be detected. Some of the pairs of 0.511-MeV photons from the positron annihilation impinge on detectors in the tomograph ring and are detected; most do not. The photon pairs are emitted 180 degrees from each other. The emission process is *isotropic*, which means that the annihilation photons are emitted with equal probability in all directions so that only a small fraction of the total number of photons emitted from the patient actually strike the tomograph detectors (Fig. 40-15).

PET scanners originally used ray information only from the nearest adjacent planes. However, with improvements in software reconstruction techniques and the elimination of septa between detector rings, the second, third, fourth, and upward adjacent planes are used to produce three-dimensional PET images. With inclusion of the additional cross-plane information, PET scanner *sensitivity* is greatly increased. Hence, the injected doses of radiopharmaceutical are significantly reduced (50% to 90% less radioactivity given) to yield PET images with a quality equivalent to that of images obtained from the original dose levels used in two-dimensional PET scanners with septa.

When pairs of photons are detected, they are counted as valid events (i.e., true positron annihilation) only if they appear at the detectors within the resolving time for the coincidence electronics. For many PET tomographs this is typically 8 to 12 nsec. If one photon is detected and no other photon is observed during that time window, the original event is discarded. This is defined as electronic collimation. No conventional lead collimators as needed with SPECT are used in PET scanners. However, thick lead shields absorb annihilation photons created out of the axial FOV before interacting with the PET detectors. These shields help to reduce random events and high singles counting events. PET scanners must operate with high sensitivity and as a result scanners must also be able to handle very high count rates with minimum *deadtime* losses.

Dual-headed coincidence SPECT systems were developed in order to offer lower cost alternatives to conventional PET ring instrumentation. No collimators were used. The pair of gamma camera heads operated in coincidence, as with conventional ring detectors, but the pair of cameras revolved together about the patient to collect data from 180 degrees of rotation. Low count rate capability and poor sensitivity limited the effectiveness of the systems. FDG was the major pharmaceutical used for dual-headed coincidence systems. Current technological developments no longer focus on dual-headed coincidence systems but rather are centered on producing conventional ring tomographs but with different scintillators and at much lower cost.

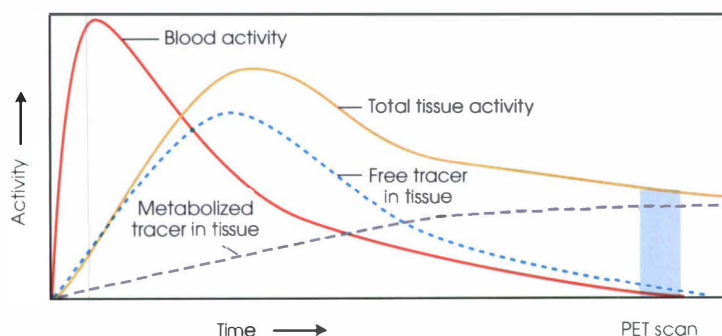


**Fig. 40-15** Side view of PET scanner, illustrating possible photon directions. Only 15% of the total number of emitted photons from the patient can be detected in a whole-body tomograph (ring diameter: 100 cm (39 inches)). This is increased to 25% for a head tomograph (ring diameter: 60 cm (24 inches)). For these estimates, the z axis coverage was considered to be 15 cm (6 inches). The actual number of detected coincidences will be less than either the 15% or 25% estimate, because the detector efficiency is not 100% (typical efficiency: 30%).

For PET procedures, data acquisition is not limited to images of tomographic count rates. For example, the creation of *quantitative* parametric images of glucose metabolism requires that the blood concentrations of the radiopharmaceutical be measured. This is accomplished by discrete or continuous arterial sampling, or *region of interest (ROI)* analysis of a sequential time series of major arterial vessels observed in reconstructed tomographic images. For arterial sampling, an indwelling catheter is placed in the radial artery. Arterial blood pressure forces blood out of the catheter for collection and radioactivity measurement. For venous sampling, blood is withdrawn through an indwelling venous catheter.

However, for obtaining *arterialized venous blood*, the patient's hand is heated to between 104° F and 108° F (40° C and 42.2° C). In this situation arterial blood is shunted directly to the venous system. The arterial concentration of radioactivity can then be assessed by measuring the venous radioactivity concentration. If plasma radioactivity measurement is required in discrete samples, the red blood cells are separated from whole blood by centrifugation and the radioactivity concentration within plasma is determined by discrete sample counting in a gamma well counter. Continuous counting is performed on whole blood by directing the blood through a radiation detector via small-bore tubing. A peristaltic pump, a syringe pump, or the subject's arterial blood pressure is used for continuous or discrete blood sampling. For ROI analysis, the arterial blood curve is generated directly from each image of a multiple-frame time-series PET scan. An ROI is placed around the arterial vessel visualized in the PET images. The average number of counts for the ROI from each frame is plotted against time. Actual blood sampling is not usually required for ROI analysis. However, a single venous (or arterial) blood sample may be taken at times when tracer equilibrium has been established between arterial and venous blood to appropriately position the blood curve on an absolute scale.

A typical set of blood and tissue curves is given in Fig. 40-16. Curves created from plasma data, as well as other information (e.g., nonradioactive plasma glucose level), are supplied to a mathematical model that appropriately describes the physiologic process being measured (i.e., metabolic rate of glucose utilization in tissue). Parametric or functional images are created by applying the model to the original PET image data.



**Fig. 40-16** Decay-corrected radioactivity curves for  $^{18}\text{F}$ -FDG in tissue and blood (plasma). Injection occurs at the origin. The blood activity rapidly peaks after the injection. The metabolized tracer ( $^{18}\text{F}$ -FDG-6- $\text{PO}_4$ ) slowly accumulates in tissue. Typical static PET scanning occurs after an incorporation time of 40 to 60 minutes (as shown by the shaded box) in which the uptake of  $^{18}\text{F}$ -FDG is balanced with the slow washout of the labeled metabolite.



## IMAGE RECONSTRUCTION AND IMAGE PROCESSING

Images are created from raw data collected as rays corresponding to each detected annihilation event. A typical image (one slice) has  $128 \times 128$  or  $256 \times 256$  *pixels*, or *picture elements*. Each pixel typically represents 2 *bytes* of information. The image storage requirement of a PET study can be computed by the following:

$$\begin{aligned} &(\text{image size})^2 \times 2 \text{ bytes} \times \\ &\quad \text{number of slices} \times \\ &\quad \text{number of frames in a dynamic scan} \end{aligned}$$

For an LCBF study, the image storage is calculated as follows:

$$\begin{aligned} &(128 \text{ pixels})^2 \times 2 \text{ bytes} \times \\ &47 \text{ slices} \times 10 \text{ frames} = \\ &15 \text{ megabytes (MB)} \end{aligned}$$

When multiple injections are contemplated for test/retest studies, the image storage requirements increase further.

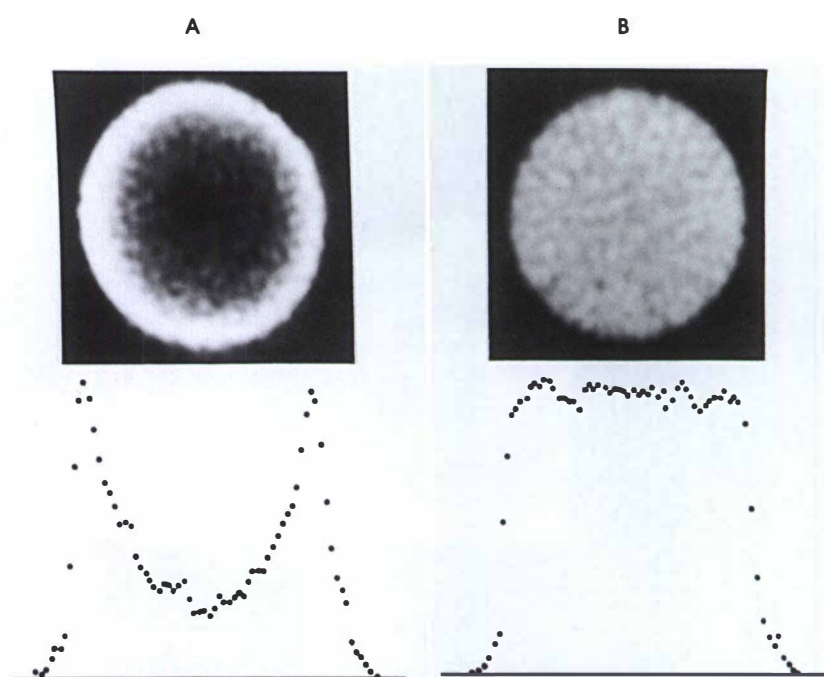
A FOV of 15 to 20 cm (6 to 8 inches in the axial direction) is required to adequately encompass the entire volume of the brain (from the top of the cerebral cortex to the base of the cerebellum) or the entire volume of the heart. New PET systems are extending this dimension to as much as 50 cm (20 inches). Array processors are used to perform the filtered back-projection or maximum likelihood (iterative) reconstruction that converts the raw *sinogram* data into PET images. This technique is similar to that employed for CT image reconstruction. However, faster and less costly desktop computers are replacing array processor technology and thereby greatly simplifying software requirements for image reconstruction.

It is very important to note that the disintegration of radionuclides follows Poisson statistics. As a result of this random process, photons from the different annihilation events may strike the tomograph detectors simultaneously. While these are registered as true events because they occur within the coincidence time window they degrade the overall image quality. A simple approximation allows for the subtraction of the random events after image acquisition and is based on the individual count rates for each detector and the coincidence resolving time (8 to 12 nsec) of the tomograph electronics according to the following relationship:

$$N_R = N_1 N_2 2\tau$$

where  $N_R$  is the random event rate,  $N_1$  and  $N_2$  are the photon counting rates for the individual detectors involved in the coincidence measurement, and  $\tau$  is the resolving time of the electronics.

Photons traversing biological tissues also undergo absorption and scatter. As shown in Fig. 40-17, an attenuation correction is applied to account for those photons that should have been detected but were not. The correction is typically based on a transmission scan acquired under computer control using a radioactive rod or pin source of  $^{68}\text{Ge}$  (germanium; 271-day half-life) that circumscribes the portion of the patient's body within the PET scanner. For brain studies, another attenuation correction technique is used, but it is less accurate. It approximates the outline of the skull with an ellipse and calculates the attenuation of photons based on the dimensions of the ellipse. A transmission scan measures the actual attenuation of photons based on the true cross-sectional area of head. The *attenuation coefficient* for 0.511-MeV photons in water-like tissue is  $0.096 \text{ cm}^2/\text{g}$ . In either case, the coincidence data for each image plane are multiplied by a matrix of numeric values (all greater than 1) within the boundaries of the skull to correct the observed sinogram to the true sinogram for losses that result from attenuation. The magnitude of the attenuation correction varies from approximately 4 in brain imaging to 32 or more in body imaging.



**Fig. 40-17** **A**, Uncorrected image of a phantom homogeneously filled with a water-soluble PET nuclide of  $^{68}\text{Ga}$  or  $^{18}\text{F}$ . **B**, Attenuation-corrected image of the same phantom. Cross-sectional cuts through the center of each image are shown in the lower panels. The attenuation correction for a phantom with a diameter of 20 cm (8 inches) can be as large as 70% in the center of the object.

Count rates from the detectors are also corrected for deadtime losses. At high count rates the detector electronics cannot handle every incoming event; therefore, some of these events are lost because the electronics are busy processing prior events. Measuring the tomograph response to known input count rates allows empirical formulations for the losses to be determined and applied to the image data. Valid corrections for deadtime losses can approach 100%.

Not every detector in the system responds exactly the same way to a uniform distribution of radioactivity. A calibration scan is performed to measure the count rate for each detector in the system from a homogeneous source. A correction mask is created from this calibration scan, and the raw data are multiplied by this mask to yield a uniform count rate image from a homogeneous (flood) source. This correction is then applied to all subsequent PET images.

For the creation of parametric images, the corrected PET scanner data and the blood radioactivity concentration data are used as input to the physiological model. Each pixel in the parametric image is assigned a physiological value for the volume represented by the pixel. As an example, pixels in an  $^{18}\text{F}$ -FDG metabolic rate image correspond to a value between 0 and 6 in units of mg of glucose utilization per minute per 100 g of tissue. For blood flow images, each pixel represents a value between 0 and 150 in units of milliliters of blood flow per minute per 100 g of tissue.

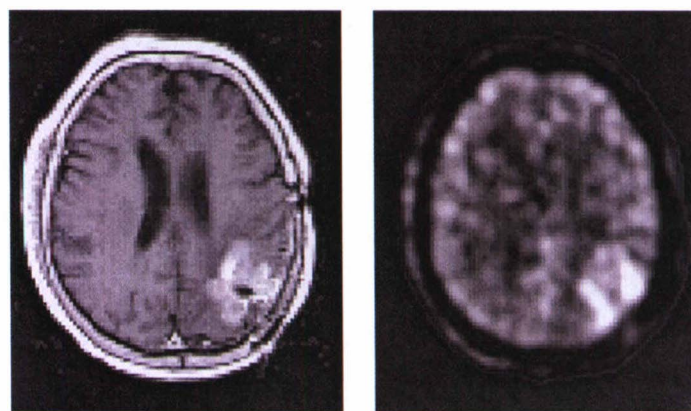
Once the raw data are converted to functional images, ROIs can be drawn on the images. Average values of counts/area or counts/pixel are determined for each ROI. Data analysis consists of correlating the physiological value obtained from the patient's PET image data with the normative data. Abnormalities are identified as either elevated or diminished values of function when compared with a standard database of similar pathology or information from normal subjects. Intrinsically, biological parameters have approximately a 15% standard deviation. For a true intersubject difference to be observed, variations in LCBF and LCMRG values must be greater than 15%. Intrasubject variability from PET studies has been shown to be about 7%. Therefore, if a research or clinical protocol can be designed so that the patient also serves as the control, greater reliability and reduced errors are achieved.

## Clinical Studies

PET imaging is relatively costly. It is best used for answering complex questions that involve locating and quantitatively assessing tissue function (Figs. 40-18 and 40-19). The use of PET as a broad-based clinical screening tool is limited since it requires a relatively long imaging time (1 to 3 hours) compared with other imaging procedures. It is important, then, that the selection of patients and normal volunteers be made according to very stringent protocols. Before each imaging procedure, subjects typically receive a brief physical examination and laboratory blood tests. Certain external landmarks are measured. In brain imaging, for example, the measurements include the head diameter and the distance from the top of the head to an imaginary line passing from the lateral canthus of the eye to the meatus of the ear (the *CM line*). For quantitative studies, a radial artery is catheterized to obtain arterial blood samples, or heated hand techniques are used to obtain arterialized venous blood. Blood curves are collected and used as input functions for the physiologic models. Patients are oriented in the scanner in the supine position, either head or feet first.

The appropriate radiopharmaceutical is injected by IV bolus, IV infusion, or a combination of the two techniques. For dynamic studies, the injection is synchronized with the start of imaging. For quantitative studies, blood samples are collected according to established protocols. For  $^{18}\text{F}$ -FDG studies, a decay-corrected plasma activity curve is constructed from blood samples (approximately  $20 \times 1$  ml samples) acquired over the entire imaging procedure (1 to  $1\frac{1}{2}$  hours) using discrete blood sampling techniques. For  $^{15}\text{O}$ - $\text{H}_2\text{O}$  studies, arterial samples are continuously withdrawn at a rate of 5 to 7 ml per minute for 2 minutes. Radioactivity detectors measure the whole-blood  $^{15}\text{O}$ - $\text{H}_2\text{O}$  concentration while the blood is being withdrawn. As much as 200 to 300 ml of blood may be drawn over a long study (5 to 10 injections of  $^{15}\text{O}$ - $\text{H}_2\text{O}$ ).

$^{18}\text{F}$ -FDG studies require a 60 to 90 minute period for incorporation of the radiopharmaceutical. Some protocols suggest that imaging tumors after 90 minutes of FDG incorporation may lead to significantly better signal to noise values in the tumor as compared with surrounding tissues. The extra incorporation time may present more difficulties in controlling the patient throughput, since it adds substantially to the overall time the patient is in the PET Center. Further, longer incorporation times and increased numbers of patients being imaged by PET translate into the need for more FDG to be available within the PET Center.



**Fig. 40-18** Comparison of images obtained using transverse MRI (left) and PET (right) in a patient with recurrent brain tumor. PET depicts high  $^{18}\text{F}$ -FDG metabolism at two locations, as indicated by the bright areas in the lower right portion of the image.



Depending on the dose injected and PET scanner sensitivity, approximately 5 to 25 minute scans for each bed position are acquired to measure the almost static distribution of  $^{18}\text{F}$ -FDG glucose metabolism in tissue after the necessary incorporation period. The total scanning procedure, including the incorporation period, takes about  $1\frac{1}{2}$  to  $2\frac{1}{2}$  hours for a single injection of  $^{18}\text{F}$ -FDG. The long half-life of  $^{18}\text{F}$  (109.8 minutes) precludes multiple injections on the same day in most cases. Whole-body images are created by piecing together PET data acquired from several scans as the bed automatically moves through the PET scanner.

For  $^{15}\text{O}$ - $\text{H}_2\text{O}$  LCBF studies, a separate injection is necessary for each axial FOV (35 to 47 slices). For research studies, several injections are often administered; data are collected that show the differences in brain blood flow between each injection. The scanning procedure takes from 40 seconds to 6 minutes for blood flow studies and depends on specific imaging protocols. From one injection to the next, a total of 10 to 15 minutes is required for the  $^{15}\text{O}$  radioactivity to decay to low enough levels to repeat the study.

After the scanning procedures are completed, the injection and arterial blood sampling catheters are removed, and the patient is permitted to leave the facility. Little residual radioactivity remains in the patient after  $^{18}\text{F}$ -FDG imaging, especially after voiding, and practically none after  $^{15}\text{O}$ - $\text{H}_2\text{O}$  studies. Patients may immediately resume normal activities.

Clinically, PET is used primarily for diagnostic imaging of cancer, specifically cancer of the lung, breast, colon, lymph system, liver, esophagus, and thyroid.  $^{18}\text{F}$ -FDG is the radiopharmaceutical of choice. Qualitative imaging (no blood sampling) is routinely performed. Slow-growing brain tumors or cancer of the prostate are not easily visualized with FDG imaging. PET plays an important role in differentiating benign from malignant processes, and it is also used for image-guided biopsy. PET is an important modality for detecting cancer recurrence in patients who have undergone surgery, chemotherapy and/or radiation treatments. Finally, PET is very effective in monitoring therapeutic interventions by rapidly yet noninvasively assessing the metabolic response of the tissues to drugs.



**Fig. 40-19** Whole-body PET images. *Left*,  $^{18}\text{F}$ -FDG sagittal image of patient with breast cancer metastasis. Numerous tumors (dark spots) are seen along the spine and sternum. *Right*, Image obtained after chemotherapy shows regression of the cancer.

**TABLE 40-4**

LCMRG and LCBF rates in normal subjects

Parametric value	Cerebellum	Temporal cortex	Visual cortex	Lef hemisphere	Right hemisphere	Whole brain
LCMRG	4.7	5.1	6.6	4.6	4.5	4.6
LCBF	60.8	65.3	82.7	54.5	55.3	54.8

LCMRG, Milligrams of glucose utilization per minute per 100 grams of tissue; LCBF, milliliters of blood flow per minute per 100 grams of tissue.

**TABLE 40-5**

Radiation dosimetry for PET studies

Organ	Absorbed dose (mrad/mCi)	
	<sup>15</sup> O-H <sub>2</sub> O*	<sup>18</sup> F-FDG†
Bladder wall	—	440
Bone	1.42	37
Bone marrow (red)	1.98	41
Brain	6.13	96
Breast	4.59	41
GI tract—stomach	1.18	44
GI tract—small intestine	3.83	48
GI tract—large intestine	3.06	59
Heart	9.84	241
Kidneys	8.15	78
Lens of eye	0.24	41
Liver	3.62	44
Lung	3.77	41
Ovary	4.61	56
Testis	3.58	56
Thyroid	6.78	36

\*From Narayana S et al: Dosimetry of (0-15) water: a physiologic approach, *Med Phys* 23:159, 1996.

†Fluorodeoxyglucose F 18 Systemic. In: *USP DI*, ed 17, Rockville, Md, 1997, United States Pharmacopel Convention, Inc.

## NORMAL VALUES

Normal volunteers studied using PET provide a database of normal values for comparison with patient data. Table 40-4 depicts local cerebral glucose metabolic rates and local cerebral blood flow rates for normal subjects. Three primary areas of brain LCMRG and LCBF are presented. The first area is associated with the control and coordination of voluntary muscle movements (cerebellum); the second area reflects the intact gray matter cortical regions (temporal cortex), which may be related to such functions as memory and fine motor movements; and the third region is responsible for decoding visual images (primary visual cortex). The visual cortex almost always shows the highest glucose utilization rates, and the cerebellum displays the lowest metabolic rates. The hemispheric averages do not differ significantly from each other or from the cerebellar values.

## RADIATION DOSIMETRY

Image quality is related to the number of events detected by the PET scanner. By administering more radioactivity, better images are usually obtained. However, two constraints limit this action. First, the PET scanner deadtime losses and random coincidences increase as greater quantities of radioactivity are placed within the FOV of the PET tomograph. More importantly, regulations place maximum limits on the radiation dose a volunteer may receive during a PET study. The total dose (mrad) delivered to an organ is calculated by multiplying the specific value in Table 40-5 by the administered amount of radioactivity (mCi).

## Future Studies

Considerable research has been conducted to study brain function with PET radiopharmaceuticals. Measurements of metabolism, blood flow, and receptor density are now considered routine. PET scanners have been specifically designed to acquire data from tumor, brain, heart, lung, and organ transplants. As the technology evolves, even greater emphasis will be placed on expanding clinical and research investigations of these tissues and organ systems.

## New Frontiers

PET technology is advancing on many fronts. FDG is routinely being produced in distribution centers throughout the United States and Europe. One or more cyclotrons at each distribution site are continuously producing F-18 fluoride for incorporation into FDG. Unit doses are shipped via common commercial carriers which also include chartered air and special ground couriers from a network of registered pharmacy distribution centers to individual PET Centers that do not have cyclotrons. Hence, to become involved in clinical PET imaging no longer requires the high financial commitment to own and operate a nuclear accelerator to produce PET radiopharmaceuticals at your local site.

New radiopharmaceuticals are being developed. Most of these are labeled with C-11. However, as the PET radiopharmaceutical distribution centers expand and are able to handle the daily demands of providing FDG to the existing and new PET Centers, production of F-18 labeled radiopharmaceuticals specifically for tumor imaging is likely to become available. FDA approval will be required before clinical imaging, but several PET manufacturers and the PET radiopharmaceutical distribution centers are sponsoring drug clinical trials to accelerate the deployment of new and viable clinical PET imaging agents. Radiolabeled choline, thymidine, dopa, estrogen receptors and numerous other biomolecules are likely candidates for new PET clinical tracers.

Mobile PET units are a reality as shown in Figs. 40-20 and 40-21. The PET scanner technology has matured to the point that the original frailty of the electronics and detector systems has been eliminated. Robust mobile units travel to community hospitals that need PET imaging but not at the level that necessitates a dedicated in-house PET scanner. By spending one to two days per week at several different hospitals in smaller communities or rural settings, the mobile PET camera best serves the needs of the oncology patients. The FDG distribution centers are necessary in this scenario since the mobile PET camera unit needs a supply of radiotracer to carry out the PET imaging study. Until the nation-wide FDG distribution centers became a reality as they now are, the use of mobile PET was extremely limited.



**Fig. 40-20** Mobile PET coach showing operator on staff stairs and elevator platform (E) in the elevated position. Elevator used to transport patients from ground level to floor level of the PET scanner unit.

(Courtesy of Shared PET Imaging, LLC.)



**Fig. 40-21** Interior of a mobile coach showing the PET workstation (foreground) and PET scanner (background).

(Courtesy Shared PET Services, LLC.)

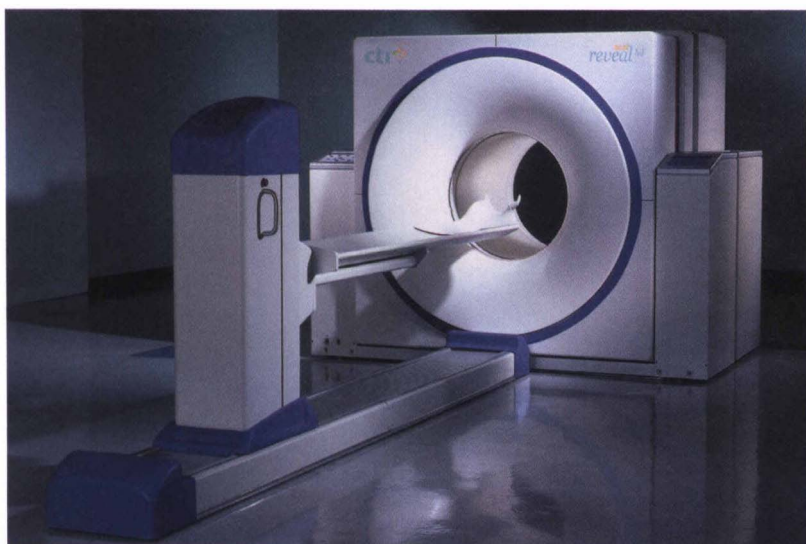


The most exciting development is the merging of the PET and CT technologies. The combined PET/CT camera shown in Fig. 40-22 couples the functional imaging capabilities of PET with the superb anatomical imaging of CT. Images from each modality are coregistered during the acquisition process and in near simultaneity. Since the images can be overlaid one on another, the position of suspected tumors can easily be identified. Suspicious metabolically active areas can now be identified anatomically from the CT information. These features are key to improving the reliability of PET interpretation. Further, metabolic and anatomical evaluation post therapy can both be accomplished in one imaging session which is likely to significantly improve patient acceptance of the procedures. For all these reasons, PET/CT is likely to become one of the most useful diagnostic procedures for assessing treatment and evaluation of cancer.

## Summary

PET is a very complex diagnostic imaging procedure. Consequently, it is both a clinical tool and a research tool. PET requires the multidisciplinary support of the physician, physicist, physiologist, chemist, engineer, software programmer, and radiographer. This imaging procedure allows numerous biological parameters in the working human body to be examined without disturbing normal-equilibrium physiology. PET measures regional function that cannot be determined by any other means, which includes CT and MRI.

Current PET studies of the brain involve the imaging of patients with epilepsy, Huntington's disease, stroke, schizophrenia, brain tumors, Alzheimer's disease, and other disorders of the central nervous system. PET studies of the heart are providing routine diagnostic information on patients with coronary artery disease by identifying viable myocardium for revascularization. But by far the greatest impact PET has made is the ability to identify highly metabolic tumors. PET scanning is critically involved in the determination of the effects of therapeutic drug regimens on tumor, and to differentiate necrosis from viable tumor. Nearly 80% of all PET imaging today is directed at tumor detection and evaluation of therapeutic intervention. Overall, human physiology will become better understood as the technology advances, yielding higher resolution instruments, new radiopharmaceuticals, and improved analysis of PET data.



**Fig. 40-22** Combined PET/CT system showing common bed that transports patient through both the high resolution CT system (front of the instrument) and PET scanner (rear of the instrument).

(Courtesy of CTI Systems, Inc.)

## Definition of Terms

**analog** PET radiopharmaceutical biochemically equivalent to a naturally occurring compound in the body.

**annihilation** Total transformation of matter into energy; occurs after the antimatter positron collides with an electron. Two photons are created; each equals the rest mass of the individual particles.

**arterialized venous blood** Arterial blood passed directly to the venous system by shunts in the capillary system after surface veins are heated to between 104° F and 108° F (40° C to 42.2° C). Blood gases from the vein under these conditions reflect near arterial levels of pO<sub>2</sub>, pCO<sub>2</sub>, and pH.

**attenuation coefficient** Number that represents the statistical reduction in photons that exit a material (N) from the value that entered the material (N<sub>0</sub>). The reduced flux is the result of scatter and absorption, which can be expressed in the following equation:  $N = N_0 e^{-\mu x}$ , where  $\mu$  is the attenuation coefficient and  $x$  is the distance traversed by the photons.

**bit** Term constructed from the words *binary digit* and referring to a single digit of a binary number; for example, the binary of 101 is composed of 3 bits.

**BGO scintillator** bismuth germanate (Bi<sub>4</sub>Ge<sub>3</sub>O<sub>12</sub>) scintillator with an efficiency twice that of sodium iodide. BGO is used in nearly all commercially produced PET scanners.

**byte** Term used to define a group of bits, usually eight, being treated as a unit by the computer.

**CM line** Canthomeatal line defined by an imaginary line drawn between the lateral canthus of the eye and meatus of the ear.

**cyclotron** Cyclic particle accelerator used to increase the kinetic energy of nuclei, such as protons and deuterons, so that radioactive materials may be produced from the resultant nuclear reactions of the ions on stable materials.

**deadtime** Time when the system electronics are already processing information from one photon interaction with a detector and cannot accept new events to be processed from other detectors.

**detector** Device that is a combination of a scintillator and photomultiplier tube. It is used to detect x-rays and gamma rays.

**deuteron** Ionized nucleus of heavy hydrogen (deuterium), which contains one proton and one neutron.

**dose** Measure of the amount of energy deposited in a known mass of tissue from ionizing radiation. *Absorbed dose* is described in units of rads; 1 rad is equal to 10<sup>-2</sup> joules/kg or 100 ergs/g.

**<sup>18</sup>F-FDG** Radioactive analog of naturally available glucose. It follows the same biochemical pathways as glucose; however, unlike glucose, it is not totally metabolized to carbon dioxide and water.

**functional image** See *parametric image*.

**gamma ray** Electromagnetic radiation or photon emitted from the decay of a radioactive nucleus. Its energy is expressed in the equivalent energy of the photon in units of electron volts (eV) or millions of electron volts (MeV).

**homeostasis** State of equilibrium of the body's internal environment.

**image coregistration** Computer technique that permits realignment of images that have been acquired from different modalities and therefore have different orientations and magnifications. With realignment, the images possess the same orientation and size. The images can then be overlaid one on the other to demonstrate similarities and differences between the images.

**isotropic** Referring to uniform emission of radiation or particles in three dimensions.

**kinetics** Movement of materials into, out of, and through biological spaces. A mathematical expression is often used to describe and quantify how substances traverse membranes or participate in biochemical reactions.

**local cerebral blood flow (LCBF)** Description of the parametric image of blood flow through the brain. It is expressed in units of milliliters of blood flow per minute per 100 g of brain tissue.

**local metabolic rate of glucose utilization (LMRG)** Units of milligrams of glucose utilization per minute per 100 g of tissue; used in conjunction with parametric images of tissues such as brain, heart, or tumor. LCMRG is specific to brain and corresponds to the local cerebral metabolic rate of glucose utilization.

**magnetic resonance imaging (MRI)** Technique of nuclear magnetic resonance (NMR) as it is applied to medical imaging. Magnetic resonance is abbreviated *MR*.

**nuclear particle accelerator** Device to produce radioactive material by accelerating ions (electrons, protons, deuterons, etc.) to high energies and projecting them toward stable materials. The list of accelerators includes linac, cyclotron, synchrotron, Van de Graaff accelerator, and betatron.

**parametric image** Image that relates anatomical position (the x and y position on an image) to a physiological parameter such as blood flow (image intensity or color). It may also be referred to as a *functional image*.

**photomultiplier tube (PMT)** Vacuum tube that transforms visible light photons into minute electron currents that are subsequently amplified by a factor of approximately 10<sup>6</sup>. Typically the output current is proportional to the energy of the incident photon.

**pixel (picture element)** Smallest indivisible part of an image matrix for display on a computer screen. Typical images may be 128 × 128, 256 × 256, or 512 × 512 pixels.

**positron** Positively charged particle emitted from neutron-deficient radioactive nuclei.

**positron emission tomography (PET)** Imaging technique that creates transaxial images of organ physiology from the simultaneous detection of positron annihilation photons.

**quantitative** Type of PET study in which the final images are not simply distributions of radioactivity but, rather, correspond to units of capillary blood flow, glucose metabolism, receptor density, etc. Studies between individuals and repeat studies in the same individual permit comparison of pixel values on an absolute scale.

**radioactivity concentration** Amount of radioactivity per unit volume. It can be expressed in units of mCi/ml (millicuries per milliliter).

**radioisotope** Synonym for *radioactive isotope*. Any isotope that is unstable undergoes decay with the emission of characteristic radiation.

**radionuclide** Nucleus of an atom that is unstable and will decay to a more stable configuration by the emission of a particle (e.g., positron, beta particle, alpha particle, etc.) or photon (gamma ray).



**radiopharmaceutical** Radioactive material that is inhaled, ingested, or injected into humans or animals; synonymous with *radiotracer*.

**radiotracer** Synonym for *radiopharmaceutical*.

**ray** Imaginary line drawn between a pair of detectors in the PET scanner or between the x-ray source and detector in a computed tomography (CT) scanner.

**reconstruction** Mathematical operation that transforms raw data acquired on a PET tomograph (sinogram) into an image with recognizable features.

**region of interest (ROI)** Area that circumscribes a desired anatomic location on a PET image. Image-processing systems permit drawing of ROIs on images. The average parametric value is computed for all pixels within the ROI and returned to the radiographer.

**resolution** Smallest separation of two point sources of radioactivity that can be distinguished for PET or single photon emission computed tomography imaging.

**scintillator** Organic or inorganic material that transforms high-energy photons such as x-rays or gamma rays into visible or nearly visible light (ultraviolet) photons for easy measurement.

**segmented region** Region of an image that has been defined and drawn based on simple intensity thresholding or other more complex mathematical expression.

**sensitivity** Ability to measure the total number of photons incident on a detector. In this case, the term is synonymous with *efficiency*. PET scanner sensitivity is often reported in units of counts per second per microcurie per milliliter in a 20-cm-diameter phantom homogeneously filled with  $^{18}\text{F}$ ,  $^{68}\text{Ge}$ , or  $^{68}\text{Ga}$ .

**septa** High-density metal collimators that separate adjacent detectors on a ring tomograph to reduce scattered photons from degrading image information.

**single-photon emission computed tomography (SPECT)** A nuclear medicine scanning procedure that measures conventional single photon gamma emissions (technetium-99m) with a specially designed rotating gamma camera.

**sinogram** Two dimensional raw data format that depicts coincidence detectors against possible rays between detectors. For each coincidence event, a specific element of the sinogram matrix is incremented by one. The sum of all events in the sinogram is the total number of events detected by the PET scanner minus any corrections that have been applied to the sinogram data.

**target** Device used to contain stable materials and subsequent radioactive materials during bombardment by high-energy nuclei from a cyclotron or other particle accelerator. The term is also applied to the material inside the device, which may be solid, liquid, or gaseous.

**transmission scan** Type of PET scan that is equivalent to a low-resolution CT scan. Attenuation is determined by rotating a rod of radioactive  $^{68}\text{Ge}$  around the subject. Photons that traverse the subject either impinge on a detector and are registered as valid counts or are attenuated (absorbed or scattered). The ratio of counts with and without the attenuating tissue in place provides the factors to correct PET scans for the loss of counts from attenuation of the 0.511-MeV photons.

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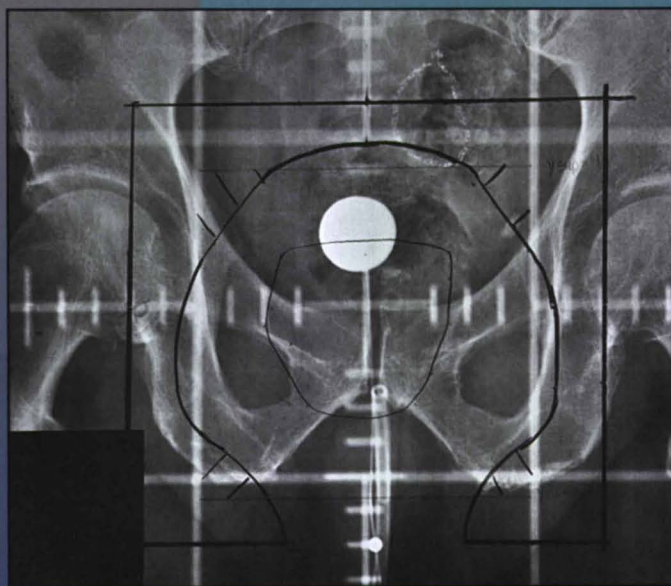


41

# RADIATION ONCOLOGY

LEILA A. BUSSMAN

AP pelvic radiograph demonstrating contrast in the bladder and its relationship to the prostate gland.



## OUTLINE

Principles of radiation oncology, 556  
Historical development, 557  
Cancer, 557  
Theory, 560  
Technical aspects, 561  
Steps in radiation oncology, 565  
Clinical applications, 571  
Future trends, 574  
Summary, 574  
Definition of terms, 575

## Principles of Radiation Oncology

*Radiation oncology*,\* or *radiation therapy*, is one of three principal modalities used in the treatment of cancer. The others are surgery and chemotherapy. In radiation therapy for malignancies, *tumors* or *lesions* are treated with *cancericidal doses* of ionizing radiation as prescribed by a *radiation oncologist*, a physician specialized in the treatment of malignant disease with radiation. The goals of the treatment are to precisely deliver a cancericidal dose of radiation to the tumor but to limit as much as possible the dose of radiation received by normal, noncancerous tissues. These dual tasks make this form of treatment complex and often challenging. Input from all members of the radiation oncology team is crucial in developing the optimum treatment plan or approach for a patient.

Cancer treatment requires a multidisciplinary approach. First, diagnostic radiologic studies such as radiographs, computed tomographic (CT) scans, and/or sonograms are obtained to acquire information about the location and anatomic extent of the tumor. Second, a tissue specimen (*biopsy*) is removed surgically. A *pathologist* then examines the tissue to determine whether the lesion is cancerous. Once cancer is diagnosed, the plan for the best treatment is determined through consultation with various *oncology* specialists (e.g., surgical *oncologist*, radiation oncologist, and/or medical oncologist).

Although radiation oncology may be used as the only method of treatment for malignant disease, a more common approach is to use radiation in conjunction with surgery, chemotherapy, or both. Some cancer patients may be treated only with surgery or chemotherapy; however, approximately 75% of all diagnosed cancer patients are treated with radiation. The choice of treatment can depend on a number of patient variables such as the patient's overall physical and emotional

condition, the histologic type of the disease, and the extent and anatomic position of the tumor. If a tumor is small and its margins are well defined, a surgical approach alone may be prescribed. If the disease is *systemic*, a chemotherapeutic approach may be chosen. Most tumors, however, exhibit degrees of size, invasion, and spread and require variations in the treatment approach that in all likelihood will include radiation treatments administered as an adjunct to or in conjunction with surgery or chemotherapy.

Radiation is generally used after surgery when a patient is deemed to be at high risk for tumor recurrence in the *surgical bed*. The risk of recurrence is considered to be increased in the following situations:

- When the surgical margin between normal tissue and cancerous tissue is minimal (less than 2 cm)
- When the margin is positive for cancer, (i.e., when cancerous tissue is not completely removed)
- When the tumor is incompletely resected because of its large size and/or its relationship with normal vital structures
- When the cancer has spread to adjacent lymph nodes

Thus the radiation can be used as definitive (primary) cancer treatment or adjuvant treatment (i.e., in combination with another form of therapy). It can also be used for *palliation*.

Radiation treatments most often are delivered on a daily basis, Monday through Friday, for 2 to 8 weeks. The length of time and the total dose of radiation delivered depend on the type of cancer being treated and the purpose of treatment (*cure* or *palliation*). Prescribed dosages of radiation can range from 2000 centigray (cGy) for palliation to 7600 cGy for curative intent (total doses). The delivery of a small amount of radiation per day (180 to 200 cGy) for a certain number of treatments, instead of one large dose, is termed *fractionation*. Because these smaller doses of radiation are more easily tolerated by normal tissue, fractionation can help minimize the acute toxic effect a patient experiences during treatment, as well as the possible long-term side effects of treatment.

The precision and accuracy necessary to administer high doses of radiation to tumors while not harming normal tissue require the combined effort of all members of the radiation oncology team. Members of this team include the radiation oncologist, a physicist, dosimetrists, radiation therapists, and oncology nurses.

The radiation oncologist prescribes the quantity of radiation and determines the anatomic region(s) to be treated. The *medical physicist* is responsible for calibration and maintenance of the radiation-producing equipment. The physicist also advises the physician about dosage calculations and complex treatment techniques. The *medical dosimetrist* devises a plan for delivering the treatments in a manner to best meet the physician's goals of irradiating the tumor while protecting vital normal structures. The *radiation therapist* is responsible for obtaining radiographs that localize the area to be treated, administering the treatments, keeping accurate records of the dose delivered each day, and monitoring the patient's physical and emotional well-being. Educating patients about potential radiation side effects and assisting patients with the management of these side effects are often the responsibilities of the oncology nurse.

The duties and responsibilities of the radiation therapist are more thoroughly described elsewhere in this chapter. In addition, more information is provided about the circumstances in which radiation is used to treat cancer. The steps necessary to prepare a patient for treatment are also described. These steps include (1) simulation, (2) evolution of the optimum treatment plan in dosimetry, and (3) treatment delivery. Current techniques and future trends are also discussed.

\*Almost all italicized words on the succeeding pages are defined at the end of this chapter.



## Historical Development

Ionizing radiation was originally used to obtain a radiographic image of internal anatomy for diagnostic purposes. The resultant image depended on many variables, including the energy of the beam, the processing techniques, the material on which the image was recorded, and most importantly the amount of energy absorbed by the various organs of the body. The transfer of energy from the beam of radiation to the biologic system and the observation of the effects of this interaction became the foundation of radiation oncology.

Two of the most obvious and sometimes immediate biologic effects observed during the early diagnostic procedures were epilation (loss of hair) and erythema (reddening of the skin). Epilation and erythema resulted primarily from the great amount of energy absorbed by the skin during radiographic procedures. These short-term radiation-induced effects afforded radiographic practitioners an opportunity to expand the use of radiation to treat conditions ranging from relatively benign maladies such as hypertrichosis (excessive hair), acne, and boils to grotesque and malignant diseases such as lupus vulgaris and skin cancer.

Ionizing radiation was first applied for the treatment of a more in-depth lesion on Jan. 29, 1896, when Dr. Émile H. Grubbé is reported to have irradiated a woman with carcinoma of the left breast. This event occurred only 3 months after the discovery of x-rays by Dr. W.K. Röntgen (Table 41-1). Although Dr. Grubbé neither expected nor observed any dramatic results from the irradiation, the event is significant simply because it occurred.

The first reported curative treatment using ionizing radiation was performed by Dr. Clarence E. Skinner of New Haven, Connecticut, in January 1902. Dr. Skinner treated a woman who had a diagnosed malignant fibrosarcoma. Over the next 2 years and 3 months the woman received a total of 136 applications of the x-rays. In April 1909, 7 years after initial application of the radiation, the woman was free of disease and considered "cured."

As data were collected, the interest in radiation therapy grew. More sophisticated equipment, a greater understanding of the effects of ionizing radiation, an appreciation for time-dose relationships, and a number of other related medical breakthroughs gave impetus to the interest in radiation therapy that led to the evolution of a distinct medical specialty—radiation oncology.

## Cancer

*Cancer* is a disease process that involves an unregulated, uncontrolled replication of cells; put more simply, the cells do not know when to stop dividing. These abnormal cells grow without regard to normal tissue. They invade adjacent tissues, destroy normal tissue, and create a mass of tumor cells. Cancerous cells can further spread by invading the lymph or blood vessels that drain the area. When tumor cells invade the lymphatic or vascular system, they are transported by that system until they become caught or lodged within a lymph node or an organ such as the liver or lungs, where secondary tumors form. The spread of cancer from the original site to different, remote parts of the body is termed metastasis. Once cancer has spread to a distant site via bloodborne metastasis, the patient is considered incurable. Therefore early detection and diagnosis are the keys to curing cancer.

An estimated 1,268,000 persons in the United States were diagnosed with cancer in 2001. This number does not include basal and squamous cell skin cancers, which have high cure rates. These types of cancer are the most common malignant diseases, with more than 1.3 million cases diagnosed in 2000. *The overall lifetime risk of developing cancer is 44% for men and about 31% for women. Cancer can occur in persons of any age, although the majority of patients are diagnosed after the age of 50 years.*

**TABLE 41-1**

Significant developments in radiation therapy

Dates	Persons	Events
1895	W.K. Röntgen	Discovery of x-rays
1896	É. Grubbé	First use of ionizing radiation in treatment of cancer
	A.H. Becquerel	Discovery of radioactive emissions by uranium compounds
1898	M. and P. Curie	Discovery of radium
1902	C.E. Skinner	First documented case of cancer "cure" using ionizing radiation
1906	J. Bergonié and L. Tribondeau	Postulation of first law of radiosensitivity
1932	E.O. Lawrence	Invention of cyclotron
1934	F. Joliot and I. Joliot-Curie	Production of artificial radioactivity
1939	E.O. Lawrence and R.S. Stone	Treatment of cancer patient with neutron beam from cyclotron
1940	D.W. Kerst	Construction of betatron
1951		Installation of first cobalt-60 teletherapy units
1952		Installation of first linear accelerator (Hammersmith Hospital, London)



The most common cancers that occur in the United States are lung, prostate, breast, and colorectal cancer. Prostate cancer is the most common malignancy in men; for women, breast cancer is the most common. In both men and women, the second and third most common cancers are lung and colorectal cancer (Table 41-2).

Cancer is the second only to heart disease as the leading cause of death in the United States. Lung cancer is the leading cause of cancer deaths for both men and women. In 2001 an estimated 31% of cancer deaths in men and 25% in women were due to lung cancer. The next most common types of terminal cancer are prostate cancer and breast cancer, which respectively account for 11% and 15% of cancer deaths in the United States.

**TABLE 41-2**  
Top five most common cancers in men and women

Men	Women
1. Prostate	Breast
2. Lung and bronchus	Lung and bronchus
3. Colon and rectum	Colon and rectum
4. Bladder	Uterus (endometrium)
5. Non-Hodgkin's	Ovary lymphomas

**RISK FACTORS**  
**External factors**

Many factors can contribute to a person's potential for the development of a *malignancy*. These factors can be external exposure to chemicals, viruses, or radiation within the environment or internal factors such as hormones, genetic mutations, and disorders of the immune system. Cancer commonly is the result of exposure to a *carcinogen*, which is a substance or material that causes cells to undergo malignant transformation and become cancerous. Some of the known carcinogenic agents are listed in Table 41-3. Cigarettes and other tobacco products are the principal cause of cancers of the lung, esophagus, oral cavity/pharynx, and bladder. Cigarette smokers are 10 times more likely to develop lung cancer than are nonsmokers. Occupational exposure to chemicals such as chromium, nickel, or arsenic can also cause lung cancer. A person who smokes and also works with chemical carcinogens is at even greater risk for developing lung cancer than is a nonsmoker. In other words, risk factors can have an additive effect, acting together to initiate or promote the development of cancer.

Another carcinogen is *ionizing radiation*. It was responsible for the development of osteogenic sarcoma in radium-dial painters in the 1920s and 1930s, and it caused the development of skin cancers in pioneer radiologists. Early radiation therapy equipment used in the treatment of cancer often induced a second malignancy in the bone. The low-energy x-rays produced by this equipment were within the photoelectric range of interactions with matter, resulting in a 3:1 preferential absorption in bone compared to soft tissue. Therefore some breast cancer patients who were irradiated developed an osteosar-

coma of their ribs after a 15- to 20-year latency period. With the advances in diagnostic and therapeutic equipment and improved knowledge of radiation physics, radiobiology, and radiation safety practices, radiation-induced malignancies have become relatively uncommon, although the potential for their development still exists. In keeping with standard radiation safety guidelines, any dose of radiation, no matter how small, significantly increases the chance of a genetic mutation.

**Internal factors**

Internal factors are causative factors over which persons have no control. Genetic mutations on individual genes and *chromosomes* have been identified as predisposing factors for the development of cancer. Mutations can be sporadic or hereditary, as in colon cancer. Chromosomal defects have also been identified in other cancers, such as leukemia, Wilms' tumor, retinoblastoma, and breast cancer. Because of their familial pattern of occurrence, breast, ovarian, and colorectal cancer are three major areas currently under study to obtain earlier diagnosis, which increases the cure rate. For example, patients with a family history of breast or ovarian cancer can be tested to see whether they have inherited the altered *BRCA-1* and *BRCA-2* genes. Patients with these altered genes are at a significantly higher risk for developing breast and ovarian cancer. Women identified as carriers of the altered genes can benefit from more intensive and early screening programs in which breast cancer may be diagnosed at a much earlier and thus more curable stage. These patients also have the option of *prophylactic surgery* to remove the breasts or ovaries. Some women, however, still develop cancer in the remaining tissue after surgery.

**TABLE 41-3**  
Carcinogenic agents and the cancers they cause

Carcinogen	Resultant cancer
Cigarette smoking	Cancers of lung, esophagus, bladder, and oral cavity/pharynx
Arsenic, chromium, nickel, hydrocarbons	Lung cancer
Ultraviolet light	Melanoma and nonmelanomatous skin cancers
Benzene	Leukemia
Ionizing radiation	Sarcomas of bone and soft tissue, skin cancer, and leukemia

### Familial adenomatous polyposis

Familial adenomatous polyposis (FAP) is a hereditary condition in which the lining of the colon becomes studded with hundreds to thousands of polyps by late adolescence. A mutation in a gene identified as the adenomatous polyposis coli (APC) gene is considered the cause of this abnormal growth of polyps. Virtually all patients with this condition eventually develop colon cancer. Furthermore, they develop cancer at a much earlier age than the normal population. Treatment involves removal of the entire colon and rectum.

### Hereditary nonpolyposis colorectal cancer

Hereditary nonpolyposis colorectal cancer (HNPCC) syndrome is a cancer that develops in the proximal colon in the absence of polyps or with fewer than five polyps. It has a familial distribution, occurring in three first-degree relatives in two generations, with at least one person being diagnosed before the age of 50 years. HNPCC has also been associated with the development of cancers of the breast, endometrium, pancreas, and biliary tract.

### Familial cancer research

Current research to identify the genes responsible for cancer will assist in detecting cancers at a much earlier stage in high-risk patients. Many institutions have familial cancer programs to provide genetic testing and counseling for persons with strong family histories of cancer. Experts assist in educating persons about their potential risk for developing cancer and the importance of screening and early detection. Genetic testing remains the patient's option, and many patients prefer not to be tested.

## TISSUE ORIGINS OF CANCER

Cancers may arise in any human tissue. However, tumors are usually categorized under six general headings according to their tissue of origin (Table 41-4). Ninety percent of cancers arise from *epithelial tissue* and are classified as *carcinomas*. Epithelial tissue lines the free internal and external surfaces of the body. Carcinomas are further subdivided into squamous cell carcinomas and adenocarcinomas based on the type of epithelium from which they arise. For example, a squamous cell carcinoma arises from the surface (squamous) epithelium of a structure. Examples of surface epithelium include the oral cavity, pharynx, bronchus, skin, and cervix. An adenocarcinoma is a cancer that develops in glandular epithelium such as that in the prostate, colon/rectum, lung, breast, or endometrium.

To facilitate the exchange of patient information from one physician to another, a system of classifying tumors based on anatomic and histologic considerations was designed by the International Union Against Cancer and the American Joint Committee for Cancer Staging and End Results Reporting. The TNM classification (Table 41-5) describes a tumor according to the size of the primary lesion (T), the involvement of the regional lymph nodes (N), and the occurrence of metastasis (M).

**TABLE 41-4**

Categorization of cancers by tissue of origin

Tissue of origin	Type of tumor
<b>Epithelium</b>	
Surface epithelium	Squamous cell carcinoma
Glandular epithelium	Adenocarcinoma
<b>Connective tissue</b>	
Bone	Osteosarcoma
Fat	Liposarcoma
<b>Lymphoreticular-hematopoietic tissue</b>	
Lymph nodes	Lymphoma
Plasma cells	Multiple myeloma
Blood cells/ bone marrow	Leukemia
<b>Nerve tissue</b>	
Glial tissue	Glioma
Neuroectoderm	Neuroblastoma
<b>Tumors of more than one tissue</b>	
Embryonic kidney	Nephroblastoma
<b>Tumors that do not fit into above categories</b>	
Testis	Seminoma
Thymus	Thymoma

**TABLE 41-5**

Application of the TNM classification system\*

Classification	Description of tumor
Stage 0 T <sub>0</sub> N <sub>0</sub> M <sub>0</sub>	Occult lesion; no evidence clinically
Stage I T <sub>1</sub> N <sub>0</sub> M <sub>0</sub>	Small lesion confined to organ of origin with no evidence of vascular and lymphatic spread or metastasis
Stage II T <sub>2</sub> N <sub>1</sub> M <sub>0</sub>	Tumor of less than 5 cm invading surrounding tissue and first-station lymph nodes but no evidence of metastasis
Stage III T <sub>3</sub> N <sub>2</sub> M <sub>0</sub>	Extensive lesion greater than 5 cm with fixation to deeper structure and with bone and lymph invasion but no evidence of metastasis
Stage IV T <sub>4</sub> N <sub>3</sub> M <sub>1</sub>	More extensive lesion than above or with distant metastasis (M <sub>1</sub> )

\*This is a generalization. Variations of the staging system exist for each tumor site.



## Theory

The biologic effectiveness of ionizing radiation in living tissue is dependent partially on the amount of energy that is deposited within the tissue and partially on the condition of the biologic system. The terms used to describe this relationship are *linear energy transfer (LET)* and *relative biologic effectiveness (RBE)*.

LET values are expressed in thousands of electron volts deposited per micron of tissue (keV/μm) and will vary depending on the type of radiation being considered. Particles, because of their mass and possible charge, tend to interact more readily with the material through which they are passing and therefore have a greater LET value. For example, a 5-MeV alpha particle has an LET value of 100 keV/mm in tissue; nonparticulate radiations such as 250-kilovolt (peak) (kVp) x-rays and 1.2-MeV gamma rays have much lower LET values: 2.0 and 0.2 keV/mm, respectively.

RBE values are determined by calculating the ratio of the dose from a standard beam of radiation to the dose required of the radiation beam in question to produce a similar biologic effect. The standard beam of radiation is 250-kVp x-rays, and the ratio is set up as follows:

$$\text{RBE} = \frac{\text{Standard beam dose to obtain effect}}{\text{Similar effect using beam in question}}$$

As the LET increases, so does the RBE. Some RBE and LET values are listed in Table 41-6.

The effectiveness of ionizing radiation on a biologic system depends not only on the amount of radiation deposited but also on the state of the biologic system. One of the first laws of radiation biology, postulated by Bergonié and Tribondeau, stated in essence that the *radiosensitivity* of a tissue is dependent on the number of *undifferentiated* cells in the tissue, the degree of mitotic activity of the tissue, and the length of time that cells of the tissue remain in active proliferation. Although exceptions exist, the preceding is true in most tissues. The primary target of ionizing radiation is the DNA molecule, and the human cell is most radiosensitive during mitosis. Current research tends to indicate that all cells are equally radiosensitive; however, the manifestation of the radiation injury occurs at different time frames (i.e., acute versus late effects).

Because tissue cells are composed primarily of water, most of the *ionization* occurs with water molecules. These events are called *indirect effects* and result in the formation of free radicals such as OH, H, and HO<sub>2</sub>. These highly reactive free radicals may recombine with no resultant biologic effect, or they may combine with other atoms and molecules to produce biochemical changes that may be deleterious to the cell. The possibility also exists that the radiation may interact with an organic molecule or atom, which may result in the inactivation of the cell; this reaction is called the *direct effect*. Because ionizing radiation is nonspecific (i.e., it interacts with normal cells as readily as with tumor cells), cellular damage will occur in both normal and abnormal tissue. The deleterious effects, however, are greater in the tumor cells because a greater percentage of these cells are undergoing mitosis; tumor cells also tend to be more poorly *differentiated*. In addition, normal cells have a greater capability for repairing sublethal damage than do tumor cells. Thus greater cell damage occurs to tumor cells than to normal cells for any given increment of dose. The effects of the interactions in either normal or tumor cells may be expressed by the following descriptions:

- Loss of reproductive ability
- Metabolic changes
- Cell transformation
- Acceleration of the aging process
- Cell mutation

Certainly the greater the number of interactions that occur, the greater the possibility of cell death.

The preceding information leads to a categorization of tumors according to their radiosensitivity:

- Very radiosensitive
  1. Gonadal germ cell tumors (seminoma of testis, dysgerminoma of ovary)
  2. Lymphoproliferative tumors (Hodgkin's and non-Hodgkin's lymphomas)
  3. Embryonal tumors (Wilms' tumor of the kidney, retinoblastoma)
- Moderately radiosensitive
  1. Epithelial tumors (squamous and basal cell carcinomas of skin)
  2. Glandular tumors (adenocarcinoma of prostate)
- Relatively radioresistant
  1. Mesenchymal tumors (sarcomas of bone and connective tissue)
  2. Nerve tumors (glioma)

Many concepts that originate in the laboratory have little practical application, but some are beginning to influence the selection of treatment modalities and the techniques of radiation oncology. As cellular function and the effects of radiation on the cell are increasingly understood, attention is being focused on the use of drugs, or simply oxygen, to enhance the effectiveness of radiation treatments.

**TABLE 41-6**

Relative biologic effectiveness (RBE) and linear energy transfer (LET) values for certain forms of radiation

Radiation	RBE	LET
250-kV x-rays	1	2.0
<sup>60</sup> Co gamma rays	0.85	0.2
14-MeV neutrons	12	75
5-MeV alpha particles	20	100



## Technical Aspects

### EXTERNAL-BEAM THERAPY AND BRACHYTHERAPY

Two major categories for the application of radiation for cancer treatment are external-beam therapy and brachytherapy. For *external-beam treatment*, the patient lies underneath a machine that emits radiation or generates a beam of x-rays. This technique is also called *teletherapy*, or long-distance treatment. Most cancer patients are treated in this fashion. However, some patients may also be treated with *brachytherapy*, a technique in which the radioactive material is placed within the patient.

The theory behind brachytherapy is to deliver low-intensity radiation over an extended period to a relatively small volume of tissue. The low intensity isotopes are placed directly into a tissue or cavity depositing radiation only a short distance, covering the tumor area but sparing surrounding normal tissue. This technique allows a higher total dose of radiation to be delivered to the tumor than is achievable with external beam radiation alone. Brachytherapy may be accomplished in any of the following ways:

1. Mould technique—placement of a *radioactive* source or sources on or in close proximity to the lesion
2. Intracavitary implant technique—placement of a radioactive source or sources in a body cavity (i.e., uterine canal and vagina).
3. Interstitial implant technique—placement of a radioactive source or sources directly into the tumor site and adjacent tissue (i.e., sarcoma in a muscle).

The majority of brachytherapy applications tend to be temporary in that the sources are left in the patient until a designated tumor dose has been attained. Two different brachytherapy systems exist. They are *low-dose-rate (LDR)* and *high-dose-rate (HDR)*. LDR brachytherapy has been the standard system for many years. A low activity isotope is utilized to deliver a dose of radiation at a slow rate of 40cGy to 500cGy per hour. This requires that patient to be hospitalized for 3 to 4 days until the desired dose is delivered.

High dose rate systems are becoming the more standard method of brachytherapy. This system utilizes a high activity isotope capable of delivering greater than 1200cGy per hour. This high dose rate allows the prescribed dose to be delivered over a period of minutes allowing this treatment to occur on an outpatient basis. Gynecologic tumors are one of the most common sites to be treated with brachytherapy, LDR or HDR. Classic LDR systems use the isotopes Cesium 137 for intracavity applications and Iridium 192 for interstitial. HDR systems utilize a high activity Iridium 192 source.

Permanent implant therapy may also be accomplished. An example of a permanent implant nuclide is iodine-125 seeds. Permanent implant nuclides have *half-lives* of hours or days and are left in the patient essentially forever. The amount and distribution of the radionuclide implanted in this manner depends on the total dose that the radiation oncologist is trying to deliver. Early stage prostate cancer is commonly treated with this technique. In most if not all cases of brachytherapy implantation, the implant is applied as part of the patient's overall treatment plan and may be preceded by or followed by additional external beam radiation therapy or possibly surgery.

### EQUIPMENT

Most radiation oncology departments have available some or all of the following units:

- 120-kVp superficial x-ray unit for treating lesions on or near the surface of the patient
- 250-kVp orthovoltage x-ray unit for moderately superficial tissues
- Cobalt-60 *gamma ray* source with an average energy of 1.25-MeV
- 6-MV-35-MV *linear accelerator* or *betatron* to serve as a source of high-energy (megavoltage) electrons and x-rays

The dose depositions of these units are compared in Fig. 41-1.

The penetrability, or energy, of an x-ray or gamma ray is totally dependent on its wavelength: the shorter the wavelength, the more penetrating the photon; conversely, the longer the wavelength, the less penetrating the photon. A low-energy beam (120 kVp or less) of radiation tends to deposit all or most of its energy on or near the surface of the patient and thus is suitable for treating lesions on or near the skin surface. In addition, with the low-energy beam a greater amount of absorption or dose deposition takes place in bone than in soft tissue.

A high-energy beam of radiation (1 MeV or greater) tends to deposit its energy throughout the entire volume of tissue irradiated, with a greater amount of dose deposition occurring at or near the entry port than at the exit port. In this energy range the dose is deposited about equally in soft tissue and bone. The high-energy (megavoltage) beam is most suitable for tumors deep beneath the body surface.

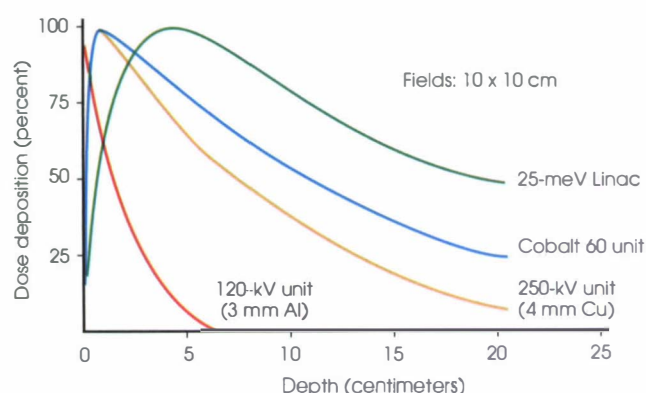


Fig. 41-1 Plot of the percent of dose deposition in relation to the depth in centimeters of tissue for various energies of photon beams.

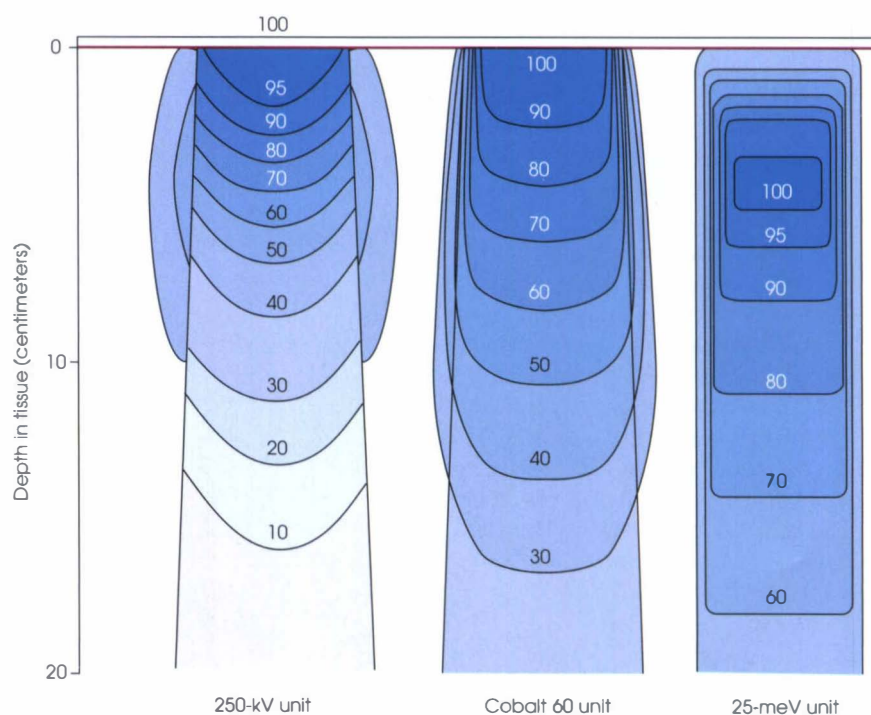
The *skin-sparing* effect, a phenomenon that occurs as the energy of a beam of radiation is increased, is of value from a therapeutic standpoint. In the superficial and orthovoltage energy range, the maximum dose occurs on the surface of the patient, and deposition of the dose decreases as the beam traverses the patient. As the energy of the beam increases into the megavoltage range, the maximum dose absorbed by the patient occurs at some point below the skin surface. The skin-sparing effect is of importance clinically because the skin is a radiosensitive organ. Excessive dose deposition to the skin can damage the skin requiring treatments to be stopped compromising treatment to the underlying tumor. The greater the energy of the beam, the more deeply the maximum dose will be deposited (Fig. 41-2).

### Cobalt-60 units

The *cobalt-60* unit was the first skin-sparing machine. It replaced the orthovoltage unit in the early 1950s because of its greater ability to treat tumors located deeper within tissues.  $^{60}\text{Co}$  is an artificially produced *isotope* formed in a nuclear *reactor* by the bombardment of stable cobalt-59 with neutrons.  $^{60}\text{Co}$  emits two gamma ray beams with an energy of 1.17 and 1.33 MeV. The unit was known as a “workhorse” because it was extremely reliable, mechanically simple, and had little downtime. It was the first radiation therapy unit to rotate 360 degrees around a patient. A machine that rotates around a fixed point, or axis, and maintains the same distance from the source of radiation is called an *isocentric machine*. All modern therapeutic units are isocentric machines. This type of machine allows the patient to remain in one position, lessening the chance for patient movement during treatment. Isocentric capabilities also assist in directing the beam precisely at the tumor while sparing normal structures.

Because  $^{60}\text{Co}$  is a radioisotope, it constantly emits radiation as it *decays* in an effort to return to a stable state. It has a half-life  $T_{1/2}$  of 5.26 years (i.e., its activity is reduced by 50% at the end of 5.26 years). Because the source decays at a rate of 1% per month, the radiation treatment time must be adjusted, resulting in longer treatment times as the source decays.

The use of cobalt units has declined significantly since the 1980s. This decline has been basically attributed to the introduction of the more sophisticated linear accelerator (linac), which has greater skin-sparing capabilities and more sharply defined radiation *fields*. The radiation beam, or field, from a cobalt unit also has large penumbra, which results in fuzzy field edges, another undesirable feature.



**Fig. 41-2** Three isodose curves showing comparison of percent dose deposition from three x-ray units of different energies. As the energy of the beam is increased, the percentage of dose deposited on surface of patient decreases.

### Linear accelerators

Linear accelerators are the most commonly used machines for cancer treatment. The first linear accelerator was developed in 1952, and first used clinically in the United States in 1956. A linear accelerator is capable of producing high-energy beams of photons (x-rays) or electrons in the range of 4 million to 35 million volts. These megavoltage photon beams allow a better distribution of dose to deep-seated tumors with better sparing of normal tissues than their earlier counterparts—the orthovoltage or cobalt units.

The photon beam is produced by accelerating a stream of electrons toward a target. When the electrons hit the target, a beam of x-rays is produced. By removing the target, the linac can also produce a beam of electrons of varying energies.

Linear accelerators can now be purchased with a single photon energy or a dual-photon machine with two x-ray beams. Typically a dual-photon energy machine consists of one low-energy (6-MeV) and one high-energy (18-MV) photon beam plus a range of electron energies (Fig. 41-3). The dual-photon energy machine gives the radiation oncologist more options in prescribing radiation treatments. As the energy of the beam increases, so does its penetrating power. Put simply, a lower-energy beam is used to treat tumors in thinner parts of the body, whereas high-energy beams are prescribed for tumors in thicker parts of the body. For example, a brain tumor or a tumor in a limb would most likely be treated with a 6-MeV beam; conversely, a pelvic malignancy would be better treated with an 18-MeV beam. Thus a small oncology center can serve its patients well by purchasing one dual-photon linear accelerator for a cost of approximately \$1.7 million instead of having to purchase two single-energy 6- and 18-MeV machines for almost \$2 million.

Electrons are advantageous over photons in that they are a more superficial form of treatment. Electrons are energy dependent, which means that they deposit their energy within a given depth of tissue and go no deeper, depending on the energy selected. For example, an 18-MeV beam has a total penetration depth of 9 cm. Any structure located deeper than 9 cm would not be appreciably affected. This is important when the radiation oncologist is trying to treat a tumor that overlies a critical structure.



**Fig. 41-3** Radiation therapists shown aligning patient and shielding block in preparation for treatment using a modern linear accelerator. X-ray beams of between 6 and 25 million volts may be produced to treat tumors in the body.



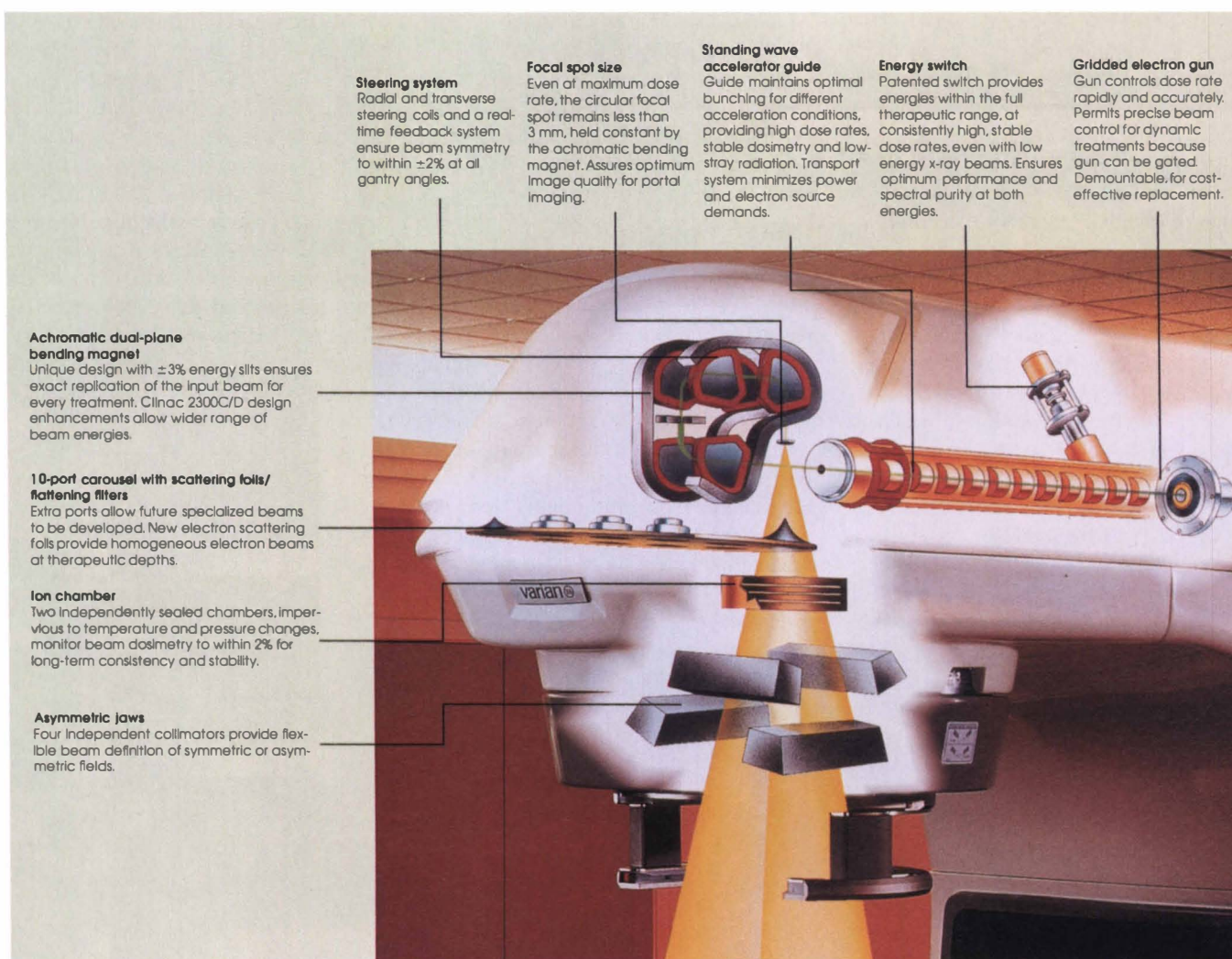


Fig. 41-4 Dualing asymmetric jaws. Note the four independent collimators.

(Courtesy Varian Associates, Palo Alto, Calif.)

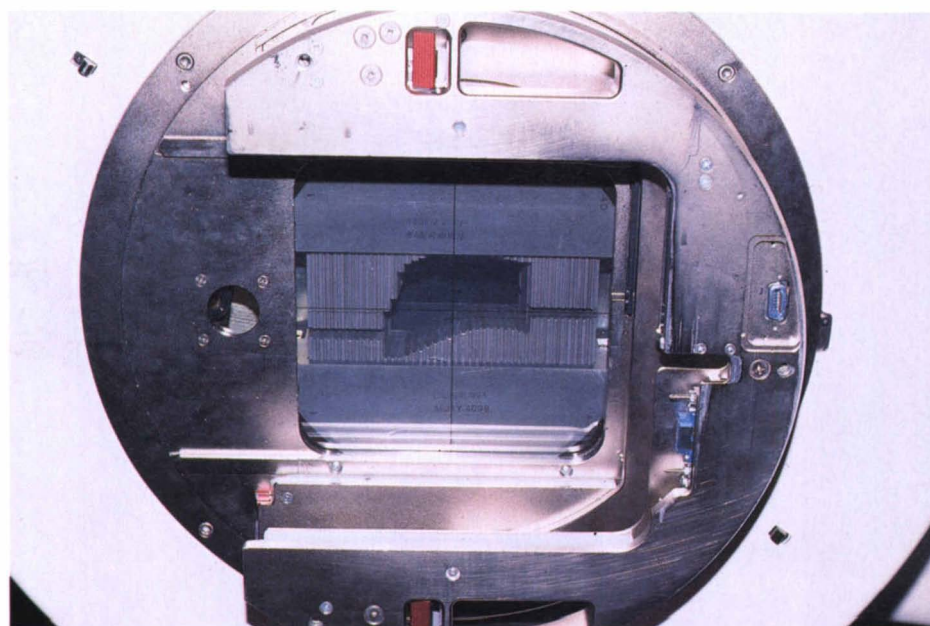


Fig. 41-5 Multileaf collimation system on the treatment head.

As with a diagnostic x-ray machine, the irradiated field of a linear accelerator is defined by a light field projected onto the patient's skin. This corresponding square or rectangle equals the length and width setting of the x-ray *collimators*. Today's modern linac is equipped with dualing *asymmetric (independent) jaws*; this allows each of the four collimator blades that define length or width to move independently (Fig. 41-4). For instance, the jaw that defines the superior extent of the field may be 7 cm from the central axis, whereas the inferior region may be at 10 cm. The total length would equal 17 cm, but it is not divided equally as it is in a diagnostic x-ray collimator. This allows the radiation oncologist to design a field that optimally covers the area of interest while sparing normal tissue. Independent collimation can also assist in reducing the total weight of lead shielding blocks normally constructed to protect normal tissues.

### Multileaf collimation

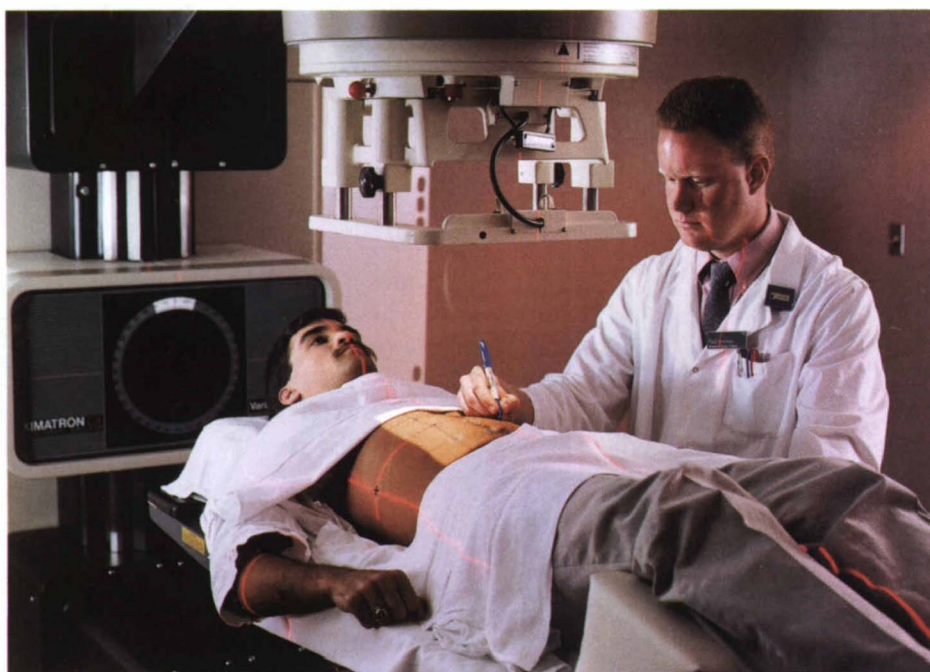
*Multileaf collimation (MLC)* is the newest and most complex beam-defining system. From 45 to 80 individual collimator blades, about  $\frac{3}{8}$  to  $\frac{3}{4}$  inch (1 to 2 cm) wide, are located within the head of the linac and can be adjusted to shape the radiation field to conform to the target volume (Fig. 41-5). The design of the field is digitized from a radiograph into a computer software program, which is transferred to the treatment room. The MLC machine receives a code that tells it how to position the individual leaves for the treatment field. Before MLC, custom-made lead blocks, or *cerrobend* blocks, were constructed to shape radiation fields and shield normal tissues from the beam of radiation. Heavy cerrobend blocks were placed within the head of the linac for each treatment field. Linacs equipped with the MLC package now receive a custom-designed field at the stroke of a computer keyboard.

## Steps in Radiation Oncology

### SIMULATION

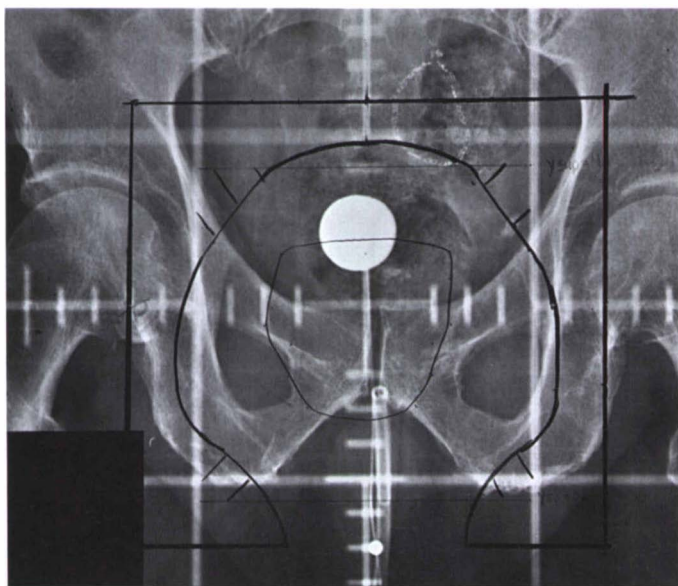
The first step of radiation therapy involves determining the volume of tissue that needs to be encompassed within the radiation field. This is done with a *simulator*, which is a diagnostic quality x-ray machine that has the same geometric and physical characteristics as a treatment unit. During simulation, the radiation oncologist uses the patient's radiographic images or the CT or MRI scan to determine the tumor's precise location and to design a treatment volume, or area. The treatment volume often includes the tumor plus a small margin, the draining lymphatics that are at risk for involvement, and a rim of normal tissue to account for patient movement.

Using fluoroscopy, the radiation therapist determines the field dimensions (length and width) and depth of isocenter as specified by the radiation oncologist. The *treatment field* outline and positioning marks are placed on the patient's skin surface (Fig. 41-6). A radiographic image is then taken of all treatment fields to facilitate treatment planning, block fabrication, and document the anatomic regions to be treated.

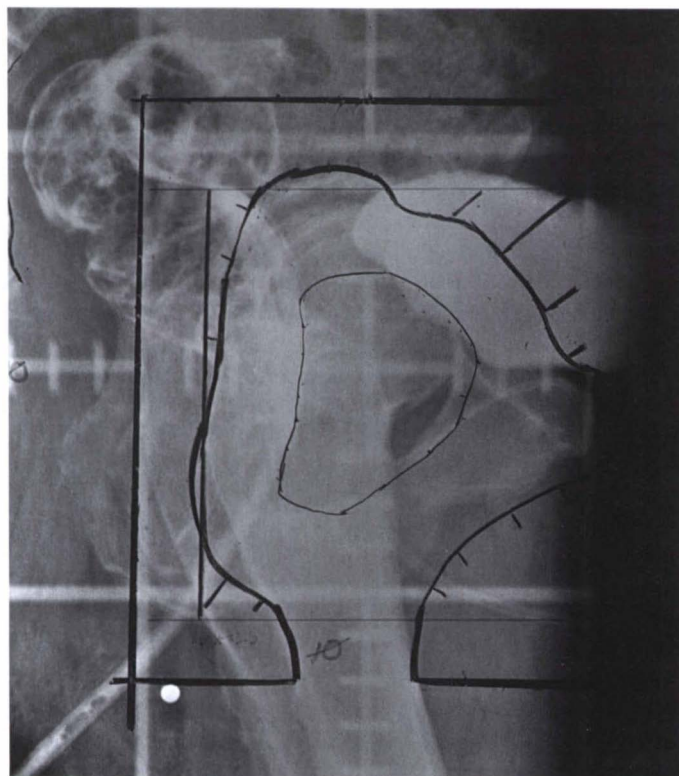


**Fig. 41-6** The radiation therapist places skin marks on the patient's skin surface for alignment of the radiation beam during treatment.





**Fig. 41-7** AP pelvic radiograph demonstrating contrast in the bladder and its relationship to the prostate gland.



**Fig. 41-8** Lateral radiograph demonstrating contrast in the rectum and bladder and their relationship to the prostate gland.

Precise measurements and details about the field dimensions, machine position, and patient positioning are recorded in the treatment chart. In some centers the treatment parameters, such as field length, width, couch, and gantry positions, are electronically captured and transferred to the treatment unit. Recording of this information is crucial so that the therapist performing the treatment can precisely reproduce the exact information.

Contrast material is often administered during a simulation to localize the area that needs to be treated or to identify vital normal structures that are to be shielded. For example, a small amount of barium is injected into the rectum of a patient with rectal cancer to assist in localizing the rectum on the simulation images. In Fig. 41-7, bladder contrast is used to assist in localizing the prostate gland, which lies directly inferior to the bladder. The rectal contrast is used to demonstrate the relationship of the rectum to the prostate in an effort to monitor and minimize the dose the rectum receives (Fig. 41-8).

Immobilization devices are also constructed as part of the simulation. One goal of simulation is to position the patient in a manner that is stable and reproducible for each of the 28 to 40 radiation treatments. It is important for a patient to hold still and maintain the same position. If the patient does not maintain the planned position, critical normal tissues may be irradiated or the tumor may not be irradiated. Immobilization devices greatly assist the therapist in correctly aligning the patient for each treatment, and many patients feel more secure when supported by these devices. Immobilization devices can be constructed for any part of the body but are most important for more mobile parts, such as the head and neck region or the limbs. Many different types of immobilization systems exist. Fig. 41-9 shows a thermoplastic device that secures the head and neck against rotation or flexion/extension.



Instead of a fluoroscopic simulator, many centers now perform virtual simulations using a CT scanner equipped with radiation oncology software tools. Before CT simulators, the films taken with the conventional simulator were done first to outline and localize areas to be treated. Following the simulation, a CT scan was done with the patient in treatment position. The CT information was then interfaced into the radiation oncology treatment planning computer for development of the treatment plan. CT sim combines the two aforementioned steps into one. First, CT scan images necessary to plan the treatment are obtained. Second, digitally reconstructed images that depict the anatomy, as in standard simulation radiographs, are processed; then the traditional marks to be placed on the patient are marked with the unit's sophisticated patient-marking system. This system enables a more accurate design of treatment fields and facilitates the implementation of three-dimensional treatment planning.

## DOSIMETRY

*Dosimetry* refers to the measurement of radiation dose, and it demonstrates how the radiation is distributed or *attenuated* throughout the patient's body (absorbing medium). The dosimetrist devises a treatment plan that best fulfills the physician's prescription for the desired dose to the *tumor/target volume* while minimizing the amount of radiation to critical normal structures or tissues.

Each organ of the body has a tolerance dose to radiation that limits the amount it can receive and still function normally. If an organ receives an excess of the tolerance dose, the organ can fail, resulting in a fatal complication. For example, the kidneys are one of the more radiosensitive structures of the body (Table 41-7). A dose in excess of 2500 cGy can result in fatal radiation nephritis. The spinal cord has a higher tolerance dose, but many tumors require even higher doses for treatment to be effective.

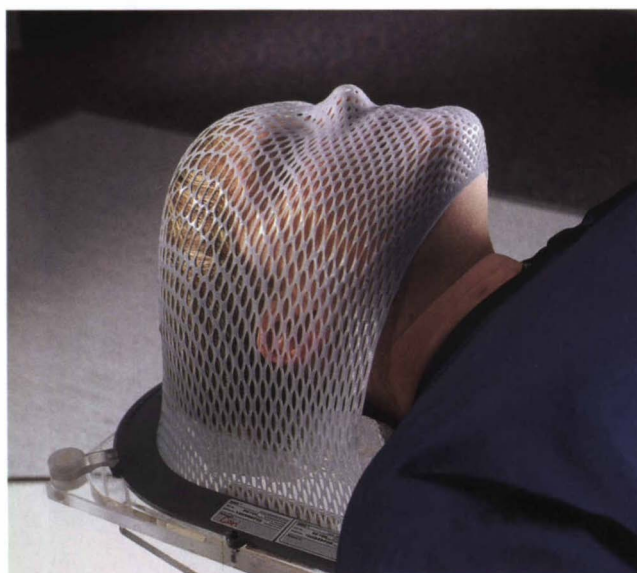
**TABLE 41-7**

Tolerance doses to radiation

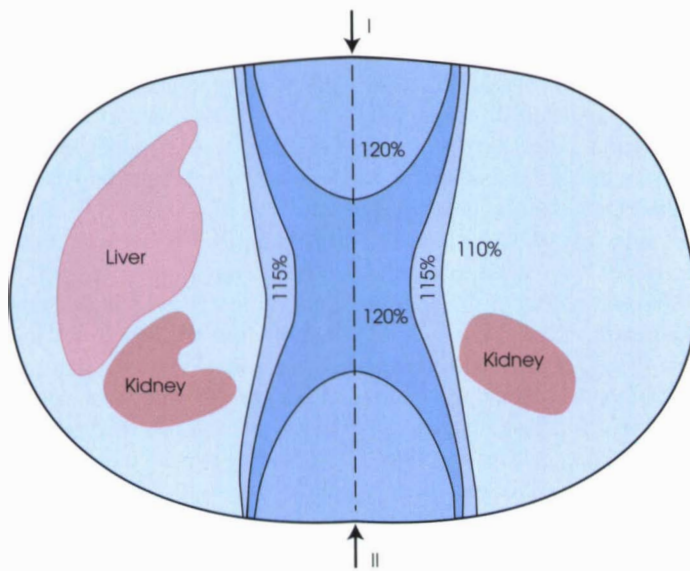
Structure	Tolerance dose
Testes	500 cGy
Ovary	500 cGy
Lung (whole lung)	1800 cGy
Kidney (whole organ)	2300 cGy
Liver (whole organ)	3500 cGy
Spinal cord (5 cm <sup>3</sup> )	4500 cGy

Precise localization of dose-limiting structures and their relationship with the target volume is critical for adequate planning. The dosimetrist must devise a plan that delivers a homogeneous dose to the tumor while not exceeding the tolerance dose of a specific organ. This task can be quite challenging. For instance, the radiation oncologist might prescribe 6000 cGy to treat lung cancer located in the mediastinum directly over the spine but must limit the spinal cord dose to 4500 cGy to prevent irreparable damage, which could result in paralysis. The dosimetrist must then devise a plan that enables combined treatment and protection to be accomplished.

The first step in dosimetry is to obtain a contour or CT scan of the patient in treatment position. A *contour* is an outline of the external surface of the patient's body at the level of the central axis (center of treatment field). This is typically performed in the transverse plane, but other planes may be used. Then the tumor volume and critical dose limiting internal structures are transferred from the simulation radiographs and drawn onto the contour (Fig. 41-10). With CT scanning, the tumor and internal structures and their relationships are directly visible. These images are then interfaced with the treatment-planning computer system for development of the plan. To obtain an even distribution of radiation to the target volume, radiation is delivered from various angles, all focused on the area of interest.

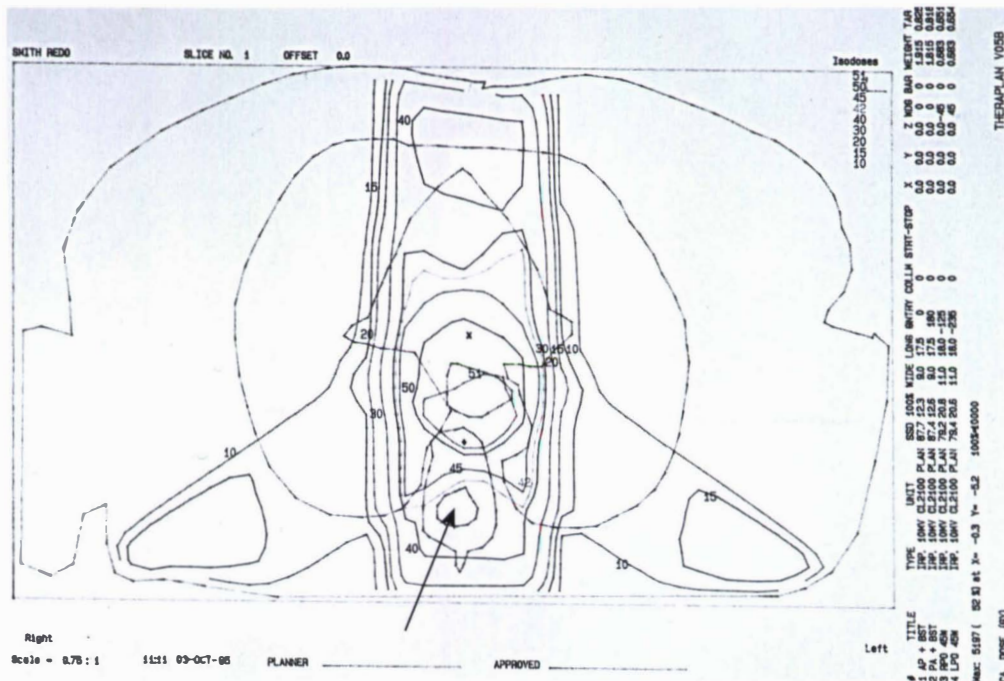


**Fig. 41-9** Aquaplast mask.



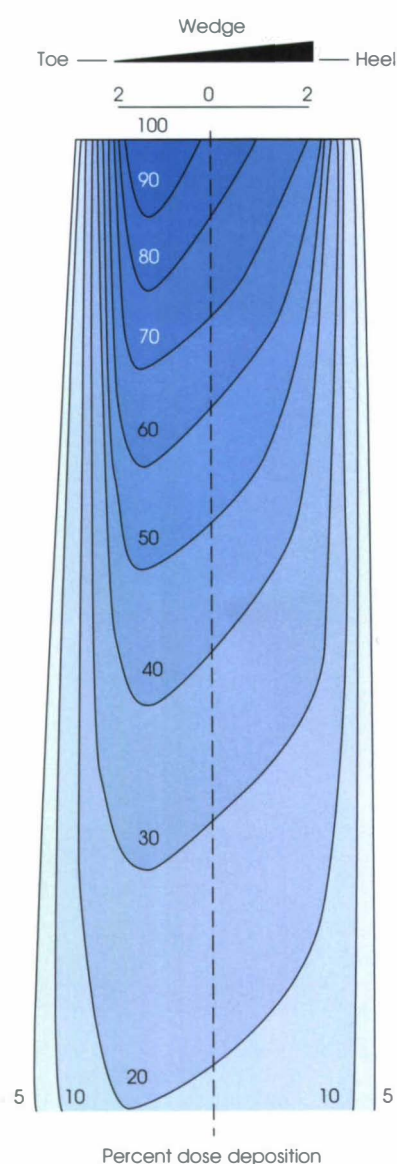
**Fig. 41-10** Opposing AP-PA ports. Summated isodose lines represent equal dose contributions from fields I and II.

The standard approach for a tumor located in the pelvis, such as prostate or rectal cancer, is the use of four fields—AP, PA, and right and left lateral. Using the treatment parameters established in the simulator, the dosimetrist enters this information into the treatment-planning computer and obtains an isodose distribution, which demonstrates how the radiation is being deposited. An *isodose line/curve* is a summation of areas of equal radiation dosage and may be stated as percentages of the total prescribed dose (see Fig. 41-10) or as actual radiation dosages in gray (Gy) (Fig. 41-11).



**Fig. 41-11** AP and two posterior oblique treatment fields are used to avoid the spinal cord (arrow) but treat the centrally located tumor. Isodose lines are expressed in the unit of radiation absorbed dose, the gray (45 gray = 4500 cGy).

The dosimetrist optimizes the plan by eliminating any areas of dose inhomogeneity such as "hot spots." A hot spot is an area of excessive radiation dose. One method to adjust for hot spots is to add a *wedge filter*. This wedge-shaped device is made of lead and is placed within the radiation beam to preferentially absorb the radiation, altering the shape of the isodose curve (Fig. 41-12). Another method of reducing hot spots is to change the weighting of the radiation beams by, for example, delivering a greater dose of radiation from the anterior field than from the posterior field.



**Fig. 41-12** Isodose curve obtained from cobalt-60 unit, with wedge placed between source and absorbing material.

Another major task of the dosimetrist is to monitor the dose that critical structures are receiving and to keep the dose within the established guidelines dictated by the physician. To avoid treating the spinal cord in the aforementioned example, the dosimetrist may angle the entry points of the radiation beams to include the target volume while not irradiating the spinal cord. The resultant fields might be right anterior oblique and left posterior oblique (RAO/LPO) fields or an anterior treatment field with two posterior obliques (see Fig. 41-10). These changes would require another simulation of the patient to document these oblique fields. The final plan directs the radiation therapist, who will treat the patient, on how to proceed. For the example presented previously (i.e., lung cancer in the mediastinum directly over the spine), the plan might consist of the following:

1. 20 treatments AP or PA fields
2. Begin off-cord obliques, 5 treatments RAO and LPO, 30 degrees off vertical
3. Reduce field size to 12 long, 5 more RAO/LPO treatments

Once the plan is complete, treatment of the patient can commence.

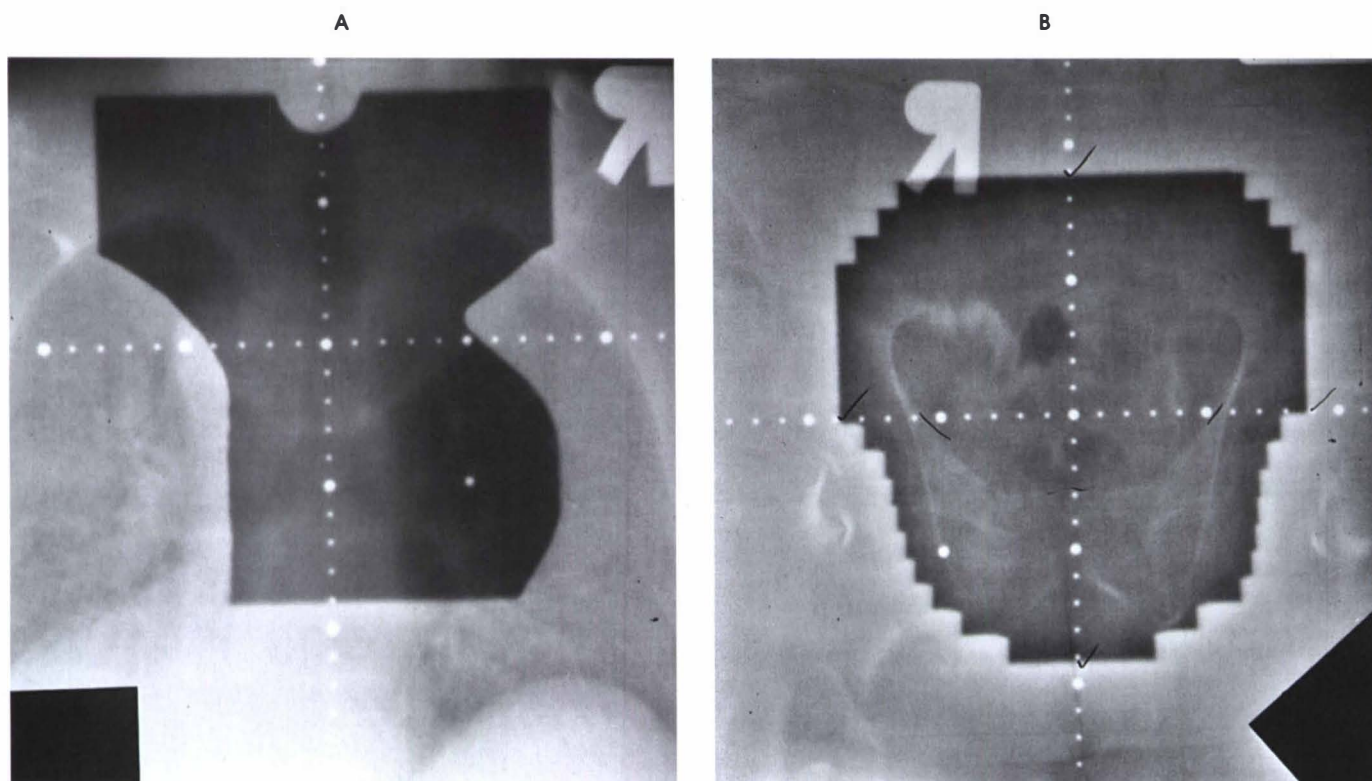


## TREATMENT

On completion of the planning stage, including simulation and dosimetry, patient treatment can begin. The radiation therapist positions the patient and aligns the skin marks according to what was recorded in the treatment chart at the time of simulation. Accuracy and attention to detail are critical for precise administration of the radiation to the patient. The therapist is responsible for interpreting the radiation oncologist's prescription and calculating the correct monitor units, or timer setting, to achieve a desired dose of radiation for each treatment field. This also involves recording the daily administration of the radiation and the cumulative dose to date.

Precision in positioning the machine, accurate placement of cerrobend blocks or wedges, and the implementation of any change in a patient's treatment plan are critical for ensuring optimum treatment. Failure to do any of these may result in an overdose to normal tissue, causing long-term side effects, or underexposure of the tumor, reducing the patient's chance for cure. Verification images, called *port films* or *images*, are taken on a weekly basis to ensure accuracy and consistent application of the radiation treatments. These port images are not of diagnostic quality because of the high-energy photon beams of the accelerator, but they are of enough detail to be compared with the simulation radiographs to verify accurate alignment of the field and blocks (Fig. 41-13).

The radiation therapist is also responsible for monitoring the patient's physical and emotional well-being. The therapist is generally the only member of the radiation oncology team who sees the patient on a daily basis. The therapist monitors the patient's progress and assists in the management of any side effects. Acting as a liaison between the patient and the physician, the therapist must know when to withhold treatment and when to refer the patient to be seen by the physician or oncology nurse for further evaluation. The daily interaction with the patient is the most rewarding aspect of the therapist's job. Putting the patient at ease and making a cancer diagnosis and subsequent treatment a less traumatic experience is a satisfying aspect of this career. Patients often express their gratitude to the therapists for their care and support.



**Fig. 41-13** **A**, AP lung image with cerrobend blocking. **B**, AP pelvis port image with multi-leaf collimation beam shaping.

## Clinical Applications

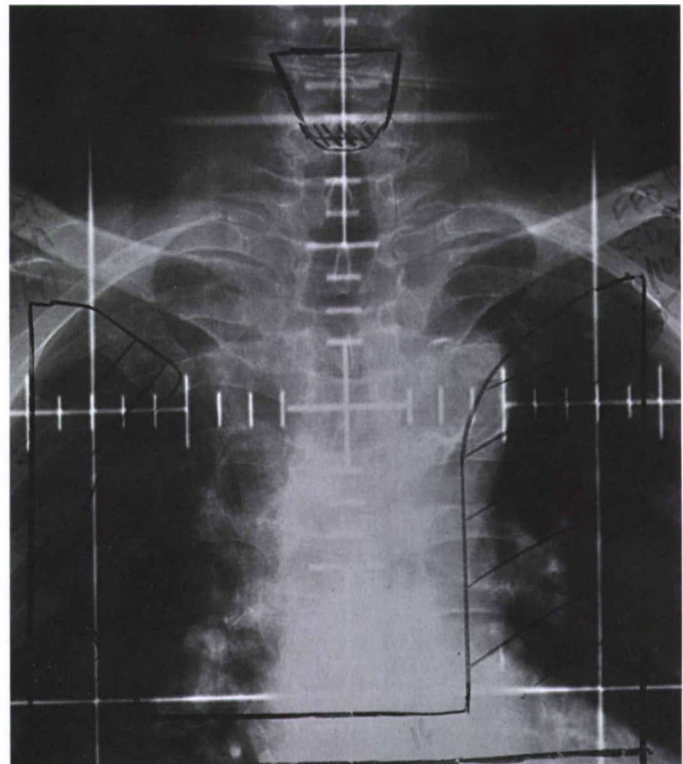
The amount of radiation prescribed depends on the type of tumor and the extent of the disease. The following are brief summaries of radiation therapy treatment techniques used in the management of some of the more common forms of cancer.

### LUNG CANCER

Treatment varies by type and stage. Radiation therapy is often used in conjunction with surgery and chemotherapy. A dose of 5000 to 6000 cGy of 10-MeV photons is often applied via a combination of AP, PA, and off-cord oblique fields. The primary tumor plus draining lymphatics are generally included in the treatment volumes (Fig. 41-14).

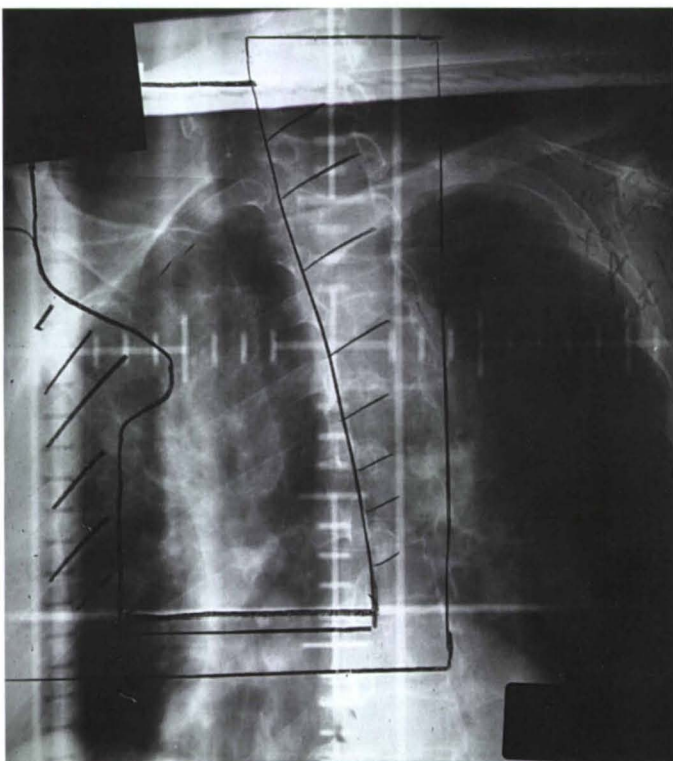
### PROSTATE CANCER

Definitive radiation therapy is a standard treatment for prostate cancer. Surgical removal of the prostate gland is another common approach to the management of this disease. A four-field technique of AP, PA, and right and left lateral ports using a megavoltage beam of 10 MV or more is often used to deliver a dose of 7000 cGy to the prostate gland.

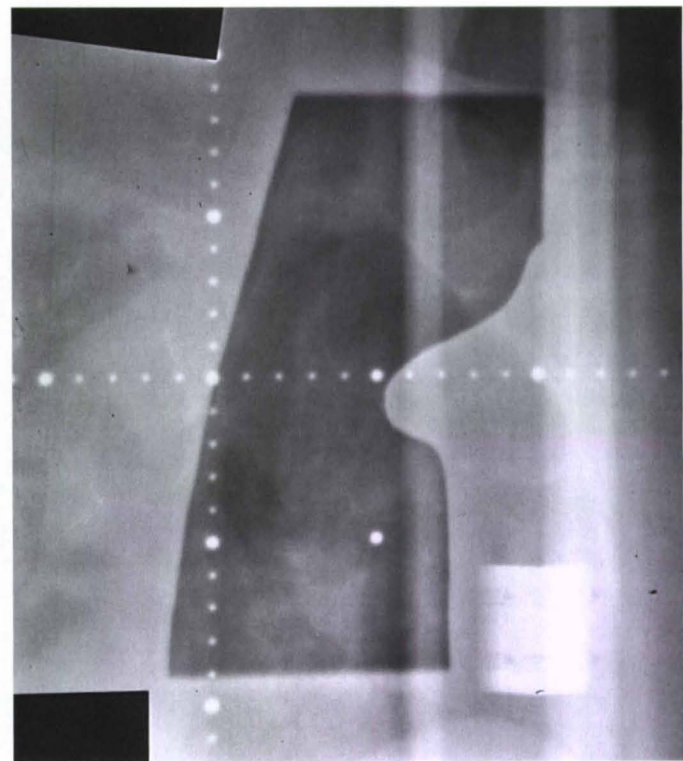


A

**Fig. 41-14** **A**, AP lung-field simulation radiograph. **B**, Off-cord oblique simulation radiograph. The striped lines in **A** and **B** indicate areas to be shielded. **C**, Off-cord oblique port radiograph.



B



C



### ORAL CAVITY CANCER

A number of approaches may be used, depending on the size and the extent of a tumor in the oral cavity. An intraoral cone may be used to deliver 6000 cGy in 4 weeks, with an orthovoltage beam used for small lesions. Larger lesions may be treated with irradiation through opposing lateral ports from a megavoltage unit, possibly followed by brachytherapy.

### CERVICAL CANCER

Early diagnosed cervical cancers can be treated with either surgery or radiation therapy. A four-field technique of AP, PA, and right and left lateral ports using a megavoltage unit, preferably 10 MV or greater, delivers 4500 to 5000 cGy in 5 weeks to an area of the primary and regional lymph nodes (Fig. 41-15). An intracavitary implant is also included in the standard treatment of cervical cancer.

### HODGKIN'S DISEASE

The age of the patient and extent of the disease may determine treatment and prognosis for Hodgkin's disease. Today, involved lymph node field irradiation following chemotherapy is more commonly used than the extended field therapy which included the lymphatic chain above and/or below the diaphragm. Treatment consists of 3500 to 4500 cGy delivered through AP-PA joints using a megavoltage unit. Chemotherapy may also be indicated for more advanced cases.

### BREAST CANCER

Using two tangential fields to the chest wall or intact breast, megavoltage radiation delivers 5000 cGy in 5 weeks (Fig. 41-16). An electron boost to the site of initial lumpectomy adds an additional 1000 cGy. Chemotherapy may also be indicated for the treatment of breast cancer.

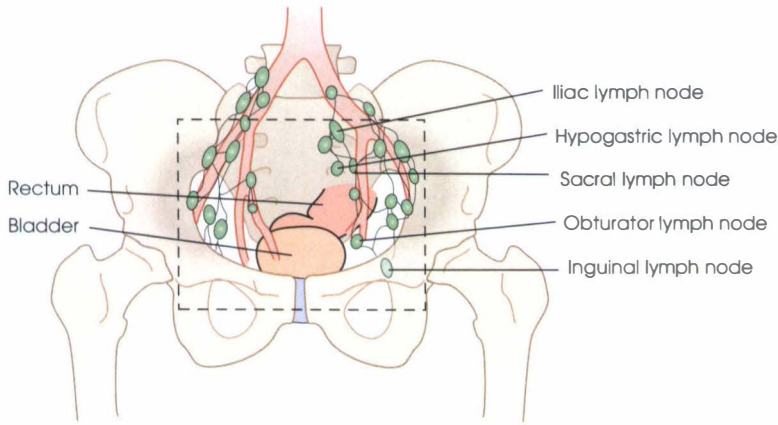


Fig. 41-15 Field used for irradiation of primary tumor and adjacent lymph nodes.

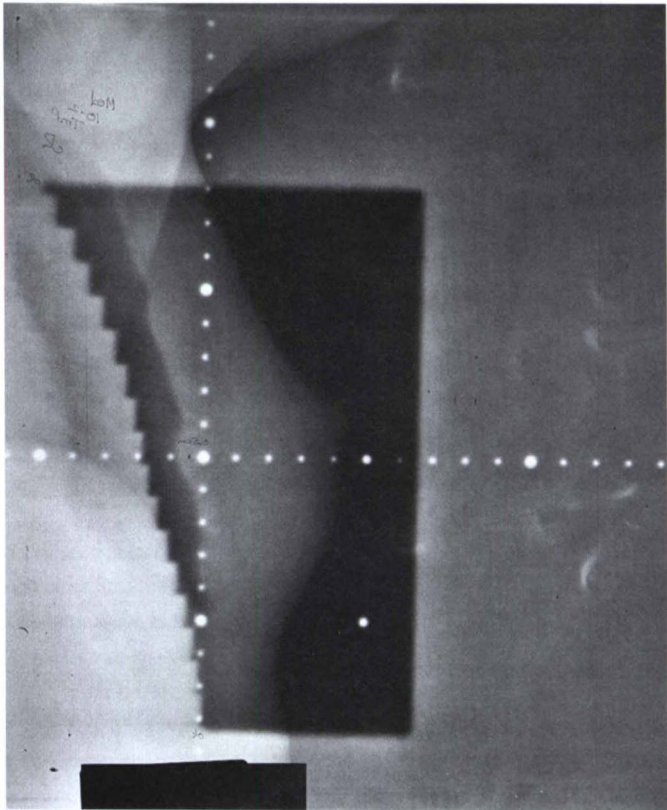
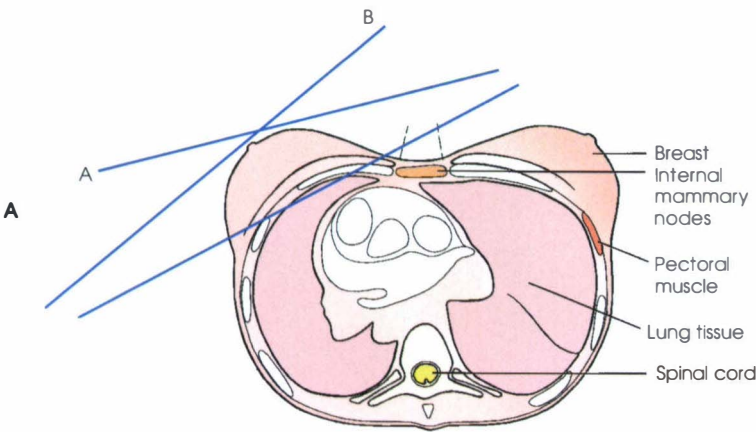


Fig. 41-16 A, Cross section of thorax showing field arrangements to tangentially irradiate the intact breast while sparing the lung (lines A and B). B, Port image of tangential breast field. Note sparing of lung tissue.



### LARYNGEAL CANCER

Cancer of the larynx is best treated with megavoltage radiation. Tumors that are confined to the true vocal cord, with normal cord mobility, have a 90% 5-year cure rate; in addition, the voice remains useful. The method of treatment is usually accomplished by using small 5 cm × 5 cm opposing lateral wedged fields and delivering a dose of 6500 cGy over a 6-week period.

### SKIN CANCER

Carcinomas of the skin are usually squamous cell or basal cell lesions and are may be treated with superficial radiation or surgery. Cure rates tend to run between 80% and 90%, and basal cell lesions less than  $\frac{3}{8}$  inch (1 cm) in diameter have a cure rate of almost 100%. The method of treatment is usually a single-field approach with attention given to shielding the uninvolved skin and delivering 4000 to 5000 cGy in a 3- to 4-week period.

### MEDULLOBLASTOMA

Children with medulloblastoma are usually referred to the radiation oncology department after a biopsy and shunt procedure. The tumor is radiosensitive, and patients who have had treatment of the entire cerebrospinal axis have a 5-year cure rate of 40% to 50%. The therapeutic approach tends to be complicated because the entire brain is irradiated with 4500 cGy, the spinal cord receives a dose of between 3500 and 4500 cGy, and the cerebellum receives an additional 1000 cGy (Fig. 41-17). This irradiation is usually accomplished with parallel opposed fields to the cranial vault and an extended single field to the spinal cord. A megavoltage unit is often used, with extreme care given to any areas of abutting fields.

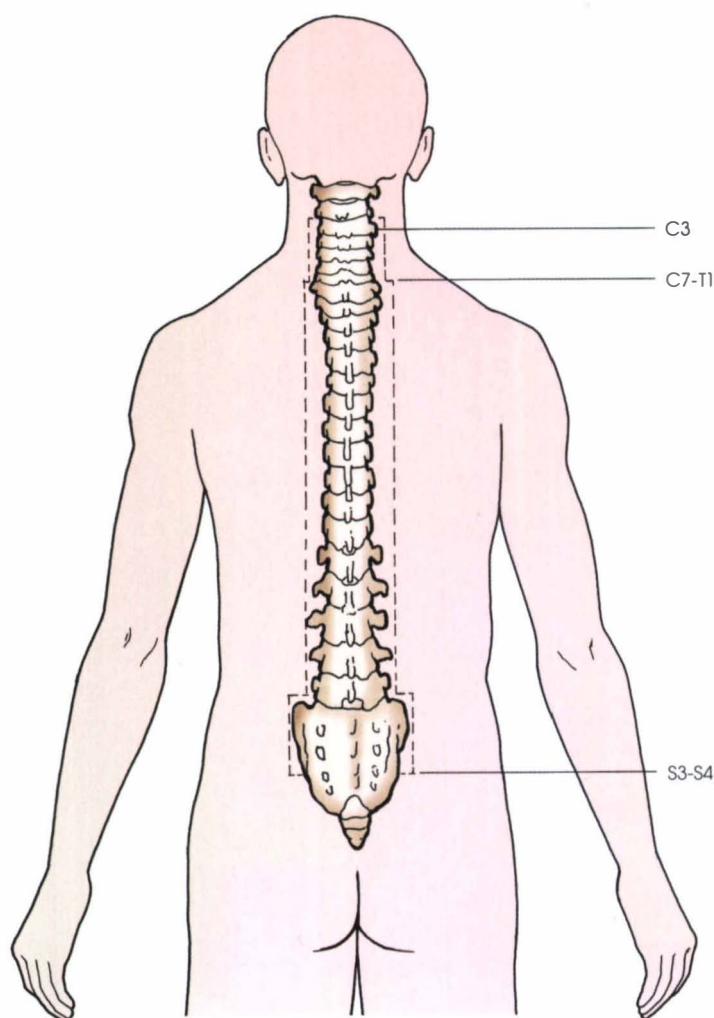


Fig. 41-17 Spinal treatment portal for medulloblastoma.

## Future Trends

Radiation therapy has entered the electronic age. Many institutions already use computer-interfaced accelerators with treatment verification software packages to ensure accurate treatment. Paperless treatment charting and filmless departments are becoming the standard design of a facility.

Advances in computer software and equipment will result in the routine implementation of three-dimensional treatment planning systems and more three-dimensional *conformal radiation* and virtual simulations. Three-dimensional treatment planning allows for the design of a beam that exactly conforms to the shape of the tumor at any plane within the body. The computer can digitally reconstruct the anatomy, which allows the dosimetrist to manipulate the image to view the tumor from any angle or plane. Such a system allows the dosimetrist to plan and design beams that are non-coplanar. The current standard method is two-dimensional planning in which the isodoses are planned from a transverse plane, as in a CT scan. The beam's eye view obtained by three-dimensional beams allows higher doses of radiation to be more safely administered by treating the cancer through multiple fields (more than four) on different planes, which reduces the amount of dose that normal tissues receive.

Three-dimensional conformal radiation uses the same principles mentioned in the previous paragraph. With this technique, the linac gantry, the couch, and the MLCs are synchronized and programmed to move as the treatment is being delivered. The collimators are programmed to automatically adjust to the treatment volume as it would be visualized from each angle or plane, further customizing the dose the tumor and normal tissue receives. This technique is now used commonly for the treatment of tumors of the brain, prostate, and head and neck sites.

## Summary

From a somewhat questionable beginning, radiation therapy has emerged as one of the primary modalities used in the treatment of malignant disease. Radiation therapy departments are currently examining and treating approximately 75% of all newly diagnosed cancer patients. Radiation oncologists and radiation therapists are integral members of the health care team that discusses and selects the appropriate treatment regimens for all cancer patients.

As the factors that initiate cellular change, growth, and spread become better understood, the radiation treatments for cancer will become even more effective. The irradiation techniques presently used may change dramatically based on this new information. In addition, new, more sophisticated radiation-producing equipment is currently under design and may lead to the reevaluation of presently accepted therapeutic techniques and dose levels. Finally, new chemotherapeutic agents are being produced that, when used by themselves or with other drugs, may enhance tumor sensitivity when used in conjunction with irradiation.

## Definition of Terms

**absorbed dose** Amount of ionizing radiation absorbed per unit of mass of irradiated material.

**accelerator (particle)** Device that accelerates charged subatomic particles to great energies. These particles or rays may be used for direct medical irradiation and basic physical research. Medical units include linear accelerators, betatrons, and cyclotrons.

**asymmetric jaws** Four independent x-ray collimators that are used to define the radiation treatment field.

**attenuation** Removal of energy from a beam of ionizing radiation when it traverses matter, accomplished by disposition of energy in matter and by deflection of energy out of the beam.

**betatron** Electron accelerator that uses magnetic induction to accelerate electrons in circular path; also capable of producing photons.

**biopsy** Removal of a small piece of tissue for examination under the microscope.

**brachytherapy** Placement of radioactive nuclide(s) in or on a neoplasm to deliver a cancericidal dose.

**cancer** Term commonly applied to malignant disease; abnormal growth of cells; neoplasm (new growth) or *-oma* (tumor).

**cancericidal dose** Dose of radiation that results in the death of cancer cells.

**carcinogen** Any cancer-producing substance or material, such as nicotine, radiation, or ingested uranium.

**carcinoma** Cancer that arises from epithelial tissue—either glandular or squamous epithelium.

**cerrobend block** Beam-shaping device made of a lead alloy that attenuates the x-ray beam, preventing exposure of normal tissue.

**chromosome** Unit of genetic information that guides cytoplasmic activities of the cell and transmits hereditary information.

**cobalt-60** Radioisotope with half-life of 5.26 years, average gamma ray energy of 1.25 MeV (range: 1.17 to 1.33 MeV), and ability to spare skin with buildup depth in tissue of 0.5 cm.

**collimator** Diaphragm or system of diaphragms made of radiation-absorbing material that defines dimension and direction of beam.

**conformal radiation** Treatment designed to deliver radiation to the exact target volume as seen on any plane (e.g., transverse, sagittal, vertex views); requires a three-dimensional treatment planning system.

**contour** Reproduction of an external body shape typically in the transverse plane at the level of the central axis of the beam; facilitates planning of radiation treatment. Other planes of interest may also be obtained.

**cure** Usually a 5-year period after completion of treatment during which time the patient exhibits no evidence of disease.

**decay or disintegration** Transformation of radioactive nucleus, resulting in emission of radiation.

**differentiation** Acquisition of cellular function/structure that differs from function/structure of original cell type.

**direct effect** Radiation that interacts with an organic molecule such as DNA, RNA, or a protein molecule. This interaction may inactivate the cell.

**dosimetry** Measurement of radiation dose in an absorbing medium.

**epithelial tissue** Cells that line the surfaces of serous and mucous membranes, including the skin.

**etiology** Study of causes of diseases.

**external-beam treatment** Delivery of radiation to a patient from a unit such as a linear accelerator in which the radiation enters the patient from the external surface of the body.

**field** Geometric area defined by collimator or radiotherapy unit at skin surface.

**fractionation** Division of total planned dose into a number of smaller doses to be given over longer period. Consideration must be given to biologic effectiveness of smaller doses.

**gamma ray** Electromagnetic radiation that originates from radioactive nucleus and causes ionization in matter; identical in properties to x-ray.

**gray (Gy)** International unit for the quantity of radiation received by the patient; previously rad. 1 cGy = 1 rad.

**grenz rays** X-rays generated at 20 kVp or less.

**half-life** Time (specific for each radioactive substance) required for radioactive material to decay to half its initial activity; types are biologic and physical.

**half-value layer** Thickness of attenuating material inserted in beam to reduce beam intensity to half of the original intensity.

**high dose rate brachytherapy** The use of a high activity radionuclide placed within the body for the treatment of cancer. Delivers greater than 1200 cGy per hour.

**independent jaws** X-ray collimator with four individual blades that can be moved independently of one another (see *asymmetric jaws*).

**indirect effect** Interaction of radiation with water molecules within the cell; results in the formation of free radicals OH, H, and HO<sub>2</sub>, which can damage the cell.

**ionization** Process in which one or more electrons are added to or removed from atoms, creating ions; can be caused by high temperatures, electrical discharges, or nuclear radiations.

**ionizing radiation** Energy emitted and transferred through matter that results in the removal of orbital electrons (e.g., x-rays or gamma rays).

**isocentric** Referring to rotation about a fixed point.

**isodoseline-curve** Curve or line drawn to connect points of identical amounts of radiation in a given field.

**isotope** Atoms that have the same atomic number but different mass number.

**lesion** Morbid change in tissue; mass of abnormal cells.

**linear accelerator** Device for accelerating charged particles, such as electrons, to produce high-energy electron or photon beams.

**linear energy transfer (LET)** Rate at which energy is deposited as it travels through matter.

**low dose rate brachytherapy** The use of a low activity radionuclide placed within the body for the treatment of cancer. Slowly deliver dose, 40 to 500 cGy per hour, to a small volume of tissue over a period of days.

**malignancy** Cancerous tumor or lesion.

**medical dosimetrist** Person responsible for calculation of the proper radiation treatment dose who assists the radiation oncologist in designing individual treatment plans.

**medical physicist** A specialist in the study of the laws of ionizing radiation and their interactions with matter.

**metastasis** Transmission of cells or groups of cells from primary tumor to site(s) elsewhere in body.

**multileaf collimator** Individual collimator rods within the treatment head of the linear accelerator that can slide inward to shape the radiation field.



**oncologist** Doctor of medicine specializing in the study of tumors.

**oncology** Study of tumors.

**palliation** To relieve symptoms; not for cure.

**pathologist** A specialist in the study of the microscopic nature of disease.

**prophylactic surgery** Preventive surgical treatment.

**radiation oncologist** Doctor of medicine specializing in use of ionizing radiation in the treatment of disease.

**radiation oncology** Medical specialty involving the treatment of cancerous lesions using ionizing radiation.

**radiation therapist** Person trained to assist and take directions from radiation oncologist in the use of ionizing radiation for the treatment of disease.

**radiation therapy** Older term used to define medical specialty of treatment with ionizing radiation.

**radioactive** Pertaining to atoms of elements that undergo spontaneous transformation, resulting in emission of radiation.

**radiocurable** Susceptibility of neoplastic cells to cure (destruction) by ionizing radiation.

**radiosensitivity** Responsiveness of cells to radiation.

**radium (ra)** Radionuclide (atomic number, 88; atomic weight, 226; half-life, 1622 years) used clinically for radiation therapy. In conjunction with its subsequent transformations, radium emits alpha and beta particles and gamma rays. In encapsulated form it is used for various intracavitary radiation therapy applications such as that for cancer of cervix.

**reactor** Cubicle in which isotopes are artificially produced.

**relative biologic effectiveness (RBE)** Compares radiation beams with different LETs and their ability to produce a specific biologic response. Dose in gray from 250 kVp beam of x-rays/dose from another type of radiation to produce the same effect.

**simulator** A diagnostic x-ray machine that has the same geometric and physical characteristics as a radiation therapy treatment unit.

**skin sparing** In megavoltage beam therapy, reduced skin injury per centigray (cGy) exposure because electron equilibrium occurs below skin; occurs from  $\frac{1}{4}$  inch to 2 inches (0.6 cm to 5 cm) deep, depending on energy.

**surgical bed** Area of excision and adjacent tissues manipulated during surgery.

**systemic** Throughout the human body.

**teletherapy** Radiation therapy technique for which source of radiation is at some distance from patient.

**treatment field** Anatomic area outlined for treatment (e.g., AP or RL pelvis).

**tumor/target volume** Portion of anatomy that includes tumor and adjacent areas of invasion.

**undifferentiation** Lack of resemblance of cells to cells of origin.

**wedge filter** Wedge-shaped beam attenuating device used to preferentially absorb the beam to alter the shape of the isodose curve.

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# TERMINOLOGY CHANGES

To make using this edition easier, the following summarizes the technical and anatomic terms that have been changed since the ninth edition. The left column contains the *new term in italics*, and the right column contains the old term. If no old term is shown, the new term is introduced for the first time in the atlas.

## **VOLUME 1**

### **General Anatomy**

*Occlusal plane*

*Interiliac plane*

### **General Body Positions**

*Sims*

*Lithotomy*

### **Chapter 6**

*tibiotalar*

talotibial

## **VOLUME 2**

### **Chapter 16**

*Retroperitoneum*

*Major duodenal papilla*

### **Chapter 18**

*Renal capsule*





# INDEX

## A

### Abdomen

abdominal sequencing, 2:84-85  
 anatomic definition of, 1:61  
 bowel preparation, 1:18  
 compression of, during alimentary canal evaluations, 2:131  
 diagnostic ultrasound of, 3:419-422  
 entrance skin exposure for, 1:48t  
 magnetic resonance imaging of, 3:406  
 mobile radiography projections of  
   AP, 3:246-249  
   in left lateral decubitus position, 3:248-249  
   in neonate  
     AP, 3:258-261  
     lateral, 3:262-263  
   in right or left dorsal decubitus position, 3:262-263  
   PA, 3:248-249  
 projections of  
   AP, 2:77, 2:80-85, 2:90  
   chart, 2:77  
   description of, 2:79  
   indications, 2:79  
   lateral, 2:77, 2:86-89  
   in left dorsal decubitus position, 2:88-89  
   in left lateral decubitus position, 2:82-83  
   overview, 2:70t  
   PA, 2:77, 2:82  
   in right dorsal decubitus position, 2:88-89  
   in right or left position, 2:86-87  
   in upright position, 2:82, 2:85  
 quadrants, 1:61  
 radiologic procedure  
   exposure technique, 2:78  
   immobilization, 2:78  
   preparation, 2:78  
   radiologic protection, 2:79  
   regions of, 1:61  
   sectional anatomy of, 3:164  
 trauma radiographs of  
   AP projection, 2:18-20  
   left lateral decubitus position, 2:20  
 Abdominal aortic aneurysm, 2:76  
 Abdominal aortography, 3:34-35, 3:38, 3:71  
 Abdominal cavity, 1:60, 2:71  
 Abdominal fistulae, 2:90  
 Abdominopelvic region, 3:150-165  
 Abduction, 1:86  
 Absorbed dose, 1:43, 3:575  
 Abuse. *see* Children, abuse of  
 Acanthion, 2:290  
 Acanthioparietal projection  
   facial bones, 2:364-365  
   for trauma, 2:364-365  
 Accelerator, 3:575

### Acetabulum

Dunlap, Swanson, and Penner method, 1:352  
 "false profile" position, 1:378  
 Judet method, 1:382-383  
 projections for  
   axiolateral, 1:352  
   overview, 1:344t  
   PA axial oblique, 1:380-381  
   in RAO and LAO position, 1:380-381  
   in RPO and LPO position, 1:382-383  
 radiologic imaging of, 1:367  
 sectional anatomy of, 3:160-161  
 Teufel method, 1:380-381  
 Achalasia, 2:127  
 Acini, 2:466  
 Acoustic impedance, 3:458  
 Acoustic neuroma, 2:296  
 Acoustic properties, 3:575  
 Acoustic shadow, 3:458  
 Acquisition rate, 3:377, 3:383  
 Acromial extremity, 1:161  
 Acromioclavicular articulation, 1:221  
   Alexander method  
     for AP axial projection, 1:202-203  
     for PA axial oblique projection, 1:204  
   anatomy of, 1:165, 1:167  
   infraspinatus insertion, 1:200  
   Pearson method, 1:200-201  
   projections for  
     AP, 1:200-201  
     AP axial, 1:202-203  
     bilateral, 1:200-201  
     chart for, 1:168  
     overview, 1:160t, 1:186t  
   in RAO or LAO position, 1:204  
 Acromion, 1:162, 1:215, 1:219  
 Adduction, 1:86  
 Adductor tubercle, 1:235  
 Adhesion, 2:259  
 Adipose capsule, 2:196  
 Adult sprue, 3:528  
 Afferent arteriole, 2:197  
 Afferent lymph vessel, 3:126  
 Aging. *see also* Elderly; Geriatrics  
   cardiovascular system changes, 3:227  
   central nervous system changes, 3:226  
   cognitive effects of, 3:224-225  
   endocrine system changes, 3:229  
   gastrointestinal system changes, 3:227  
   genitourinary system changes, 3:228  
   health complaints associated with, 3:224b  
   hematological system changes, 3:228  
   immune system changes, 3:227  
   integumentary system changes, 3:225  
   musculoskeletal system changes, 3:226  
   physical effects of, 3:223-224  
   physiology of, 3:225-229

### Aging—*cont'd*

  respiratory system changes, 3:228  
   sensory system changes, 3:226  
   social effects of, 3:220-223  
   systemic changes associated with, 3:225-229  
 Air calibration, 3:352  
 Ala, 1:405  
 ALARA, 1:42, 3:528  
 Alexander method, for acromioclavicular articulations, 1:186t  
   AP axial, 1:202-203  
   PA axial oblique, 1:204  
 Algorithm, 3:352  
 Alimentary canal  
   anatomy of, 2:72, 2:119  
   components of, 2:119  
   examination procedure  
     contrast media, 2:128-130  
     equipment, 2:131  
     examining room preparation, 2:132  
     exposure time, 2:132  
     radiologic apparatus, 2:131  
   gastrointestinal transit, 2:128  
   radiation protection, 2:133  
   regions of, 2:119  
 Alpha particle, 3:485  
 Alveolar process, 2:290  
 Alveoli, 1:532-533  
 Alzheimer's disease, 3:224  
 American Registry of Radiologic Technologists, 1:75  
 American Society of Radiologic Technologists  
   ethics, 1:2  
 A-mode, 3:458  
 Anal canal, 2:125  
 Analog, 3:370, 3:553  
 Analog-to-digital conversion, 3:370  
 Anastomose, 3:126  
 Anatomic markers, 1:24-25  
 Anatomic position  
   anteroposterior, 1:9-1:10  
   definition of, 1:7  
   illustration of, 1:7-8  
   lateral, 1:10-11  
   oblique, 1:12  
   posteroanterior, 1:9-1:10  
   relationship terms, 1:75  
 Anatomic snuffbox, 1:92  
 Anatomy, 1:58  
 Anechoic, 3:458  
 Aneurysm, 3:126  
 Angina pectoris, 3:126  
 Angiography  
   catheterization, 3:30-32  
   central nervous system use, 3:13-14  
   cerebral  
     anatomic considerations, 3:50-52

- Angiography—*cont'd*  
 cerebral—*cont'd*  
   anterior circulation, projections of  
     AP axial, 3:60-63  
     AP axial oblique, 3:61-62  
     lateral projection, 3:59  
   aortic arch angiogram, 3:58  
   circulation time, 3:54  
   definition of, 3:126  
   equipment, 3:55  
   examining room preparation, 3:56  
   imaging program for, 3:54  
   patient positioning for, 3:56-57  
   patient preparation, 3:55  
   posterior circulation, projections of  
     AP axial, 3:65  
     lateral, 3:64  
     submentovertical, 3:66-67  
     radiation protection, 3:56  
     technique, 3:53  
 computed tomography, 3:346-347  
 contrast media for  
   injection techniques, 3:27  
   types of, 3:27  
 definition of, 3:126, 3:383  
 digital subtraction, 3:14  
   definition of, 3:383  
   equipment and apparatus for, 3:375-376  
   historical development, 3:374  
   image postprocessing  
     analytic tools, 3:379  
     contrast and brightness adjustment, 3:378  
   edge enhancement, 3:379  
   image zoom, 3:379  
   landmarking, 3:379  
   pixel shifting, 3:378  
   remasking, 3:378  
   unsubtracted images, 3:378  
   view tracing, 3:379  
 intraarterial, 3:374, 3:380-381  
 intravenous, 3:374, 3:381  
 pediatric use, 3:214  
 principles of, 3:374  
 procedure, 3:376-377  
 programming of, 3:30  
 road mapping using, 3:381  
 system for, 3:375-376  
 equipment, 3:13, 3:27-28  
 film programming, 3:30  
 historical development of, 3:26  
 indications, 3:13, 3:26  
 magnetic resonance, 3:16  
 magnification, 3:29  
 patient care, 3:32  
 peripheral, 3:46-49  
 personnel team for, 3:32  
 radionuclide, 3:479  
 terminology associated with, 3:26  
 venography  
   central, 3:43-44  
   hepatic, 3:45  
   lower limb, 3:48-49  
   renal, 3:46  
   upper limb, 3:47  
   visceral, 3:33-35  
 Angioplasty  
   balloon, 3:69-70, 3:72  
   laser-tipped, 3:72  
   percutaneous transluminal coronary  
     catheters for, 3:69  
     definition of, 3:128  
     description of, 3:68, 3:73, 3:115  
     procedure, 3:68-73, 3:115-118  
     thermal, 3:72  
     transluminal, 3:70  
 Angle of incidence, 3:458
- Angular notch, 2:120
- Ankle  
   anatomy of, 1:239-240  
   magnetic resonance imaging of, 3:409  
   mortise joint, 1:296-297  
   projections for  
     AP, 1:291, 1:299, 1:340-341  
     AP oblique, 1:295-298  
     chart, 1:243  
     lateral, 1:292-294  
     in lateral rotation, 1:298  
     in lateromedial position, 1:294  
     in medial rotation, 1:295-297  
     in mediolateral position, 1:292-293  
     overview, 1:228t-229t  
     standing, 1:300-301  
     weight bearing method, 1:300-301  
   stress method, 1:299
- Ankylosing spondylitis, 1:353, 1:408
- Annihilation, 3:553
- Annulus fibrosus, 1:396
- Anomaly, 3:126
- Antenna, 3:413
- Anterior, 1:75
- Anterior cerebral arteries, 3:134
- Anterior cruciate ligament  
   anatomy of, 1:236  
   double-contrast arthrography of, 1:589
- Anterior pelvic bones, 1:344t
- Anterior superior iliac spine  
   anatomy of, 1:345  
   radiologic imaging of, 1:356
- Anteroposterior position  
   description of, 1:10  
   illustration of, 1:9
- Anteroposterior projection. *see also specific anatomy, projections of*  
   description of, 1:76-77  
   illustration of, 1:77
- Anthraxosis, 1:538
- Anthropomorphic, 3:528
- Antisepsis, 3:303
- Antiseptics, 1:16
- Anus, 2:125
- Aorta  
   anatomy of, 3:21  
   sectional, 3:146-147, 3:151-153, 3:155, 3:157, 3:164  
   ascending, 3:23, 3:144-145  
   descending, 3:144-145
- Aortic arch  
   angiogram, 3:58  
   sectional anatomy of, 3:149
- Aortic dissection, 3:126
- Aortography  
   abdominal, 3:34-35, 3:38  
   description of, 3:33  
   thoracic, 3:33
- Aperture, 3:352
- Appendicitis, 2:76, 2:127
- Appendicular skeleton  
   components of, 1:66t  
   functions of, 1:66  
   schematic representation of, 1:67
- Appendix, 2:124
- Apple method, for glenoid cavity, 1:192-193
- Arcelin method, for petromastoid portion imaging, 2:440-441
- Archiving, 3:336, 3:352
- Arch of foot, 1:270-271
- Areola, 2:465
- Arm  
   anatomy of, 1:94  
   length measurements of, 1:582
- Arrhythmia, 3:126
- Arrhythmogenic, 3:126
- Arterialized venous blood, 3:553
- Arteries  
   coronary, 3:23  
   definition of, 3:126  
   diagnostic ultrasound of, 3:450-451  
   function of, 3:21  
   systemic, 3:23
- Arteriography  
   aortofemoral, 3:48-49  
   celiac, 3:38  
   definition of, 3:126  
   femoral, 3:294-295  
   hepatic, 3:39  
   inferior mesenteric, 3:41  
   pulmonary, 3:36-37  
   renal, 3:42  
   splenic, 3:40  
   superior mesenteric, 3:41  
   tibial, 3:294-295  
   upper limb, 3:46-47
- Arterioles, 3:21, 3:126
- Arteriosclerotic, 3:126
- Arteriotomy, 3:126
- Arteriovenous malformation, 3:126
- Arthrography, contrast  
   anesthetic for, 1:585  
   computed tomography and, concomitant use of, 1:593  
   description of, 1:584
- hip  
   in adults, 1:590-591  
   in children, 1:590  
   dislocations, 1:585  
   indications, 1:590  
   subtraction technique, 1:590-591
- knee  
   double-contrast arthrography, 1:588-589  
   using vertical ray method, 1:586-587  
   pneumoarthrography, 1:585  
   shoulder, 1:592-593  
   temporomandibular joint, 1:594-595  
   wrist, 1:590
- Arthrology, 1:70
- Articular capsule, 1:166
- Articular cartilage, 1:396
- Articular tubercle, 2:286
- Artifacts, 3:352, 3:370, 3:383, 3:413, 3:458
- Asbestosis, 1:538
- Ascending aorta, 3:23, 3:144-145
- Ascending colon, 3:157
- Asepsis, 3:303
- Aseptic technique, 3:303
- As low as reasonably achievable. *see* ALARA
- Aspiration pneumonia, 1:538
- Asterion, 2:277
- Asthenic body habitus, 1:63-65
- Asymmetric laws, 3:575
- Atelectasis, 1:538
- Atherectomy  
   definition of, 3:126  
   devices for, 3:117  
   directional coronary, 3:117, 3:127  
   percutaneous, 3:72  
   rotational burr, 3:117, 3:128  
   transluminal extraction, 3:117-118, 3:128
- Atheromatous, 3:126
- Atherosclerosis, 3:126
- Atlantoaxial joint, 1:406
- Atlanto-occipital articulations  
   Buetti method, 1:411  
   projections of  
     AP oblique, 1:410-411  
     overview, 1:392t  
     PA, 1:412  
     with right and left head rotations, 1:410-411



- Atlas**  
 anatomy of, 1:397  
 dens and, PA projection of, 1:416  
 open-mouth technique, 1:414-415  
 projections of  
   AP, 1:414-415  
   chart, 1:409  
   lateral, 1:418-419  
   overview, 1:392t  
   in right or left position, 1:418-419
- Atom, 3:485**
- Atria**  
 anatomy of, 3:22-23  
   sectional, 3:146-147  
 definition of, 3:126
- Attenuation, 3:413, 3:458, 3:575**
- Attenuation coefficient, 3:352, 3:553**
- Attenuation compensation, 3:458**
- Attire**  
 for operating room, 3:269  
 patient, 1:20  
 for surgical team members, 3:268-269
- Auditory ossicles, 2:289**
- Auditory tube, 2:289**
- Augmented breast**  
 magnetic resonance imaging of, 2:481  
 mammography of  
   breast cancer detection rate decreases, 2:480  
   craniocaudal projection  
     with full implant, 2:482-483  
     with implant displaced, 2:484-485  
   Eklund technique, 2:481  
   mediolateral oblique projection  
     with full implant, 2:486  
     with implant displaced, 2:487  
 sonography of, 2:481
- Automatic exposure control, 1:35, 1:38**
- Axial, 3:352**
- Axial plane, 1:58**
- Axial projection. *see also specific anatomy, projections of***  
 description of, 1:77  
 illustration of, 1:77
- Axial skeleton**  
 components of, 1:66t  
 functions of, 1:66  
 schematic representation of, 1:67
- Axillary lymph nodes, 2:466, 2:492**
- Axis**  
 anatomy of, 1:397  
 open-mouth technique, 1:414-415  
 projections of  
   chart, 1:409  
   lateral, 1:418-419  
   overview, 1:392t  
   in right or left position, 1:418-419
- Azygos vein, 3:144-147**
- B**
- Babygram, 3:184**
- Ball and socket joint, 1:72-1:73**
- Balloon atrial septostomy, 3:122**
- Barium fluorohalide, 3:370**
- Barium sulfate. *see also Contrast media***  
 description of, 2:128  
 diagnostic uses  
   alimentary canal, 2:128-129  
   cardiac studies, 1:553, 1:557, 1:561  
   esophagus, 2:133-134  
   gastrointestinal series, 2:138  
   small intestine, 2:157  
   stomach, 2:138  
   for enteroclysis, 2:161
- Barrett's esophagus, 2:127**
- Basal fracture, 2:296**
- Basal nuclei, 3:134, 3:140**
- Basilar artery, 3:135, 3:139**
- Béclère method, for intercondylar fossa, 1:324-325**
- Becquerel, 3:466, 3:485**
- Benadryl. *see* Diphenhydramine hydrochloride**
- Benign prostatic hyperplasia, 2:200**
- Bennett's fracture, 1:99**
- Bertel method, for inferior orbital sulci imaging, 2:340-341**
- Beta particle, 3:485**
- Betatron, 3:575**
- Bezoar, 2:127**
- BGO scintillator, 3:553**
- Biceps brachii, 1:166**
- Bifurcation, 3:127**
- Bile, 2:72, 2:74**
- Biliary stenosis, 2:76**
- Biliary tract**  
 anatomy of, 2:73  
 drainage procedure, 2:111  
 evaluations of  
   indications, 2:94  
   technical requirements, 2:94-95  
 projections of  
   chart, 2:77  
   contrast agents, 2:91-93  
   in LAO position, 2:104-105  
   lateral, 2:77, 2:104-105  
   overview, 2:70t  
   PA, 2:77, 2:101-103  
   PA oblique, 2:77, 2:104-105  
   in prone position, 2:101  
   in right lateral position, 2:104-105  
   in upright position, 2:101-102
- Biologic Effects of Ionizing Radiation Committee, 1:42-1:42t**
- Biopsy, 3:575**
- Bioprobe catheter, 3:113**
- Biparietal diameter, 3:447, 3:458**
- Biphasic examination of stomach, 2:141**
- Biplane, 3:127**
- Biplane imaging system, 3:28**
- Bit, 3:553**
- Blackett-Healy method**  
 for subscapular insertion, 1:199  
 for teres minor insertion, 1:198
- Black lung, 1:538**
- Bladder. *see* Urinary bladder**
- Blood-brain barrier, 3:485**
- Blowout fracture, 2:296**
- Blunt trauma, 2:2**
- B-mode, 3:458**
- Body cavities**  
 abdominal, 1:60  
 thoracic, 1:60
- Body composition, 3:528**
- Body habitus**  
 exposure factors and, 1:63  
 gallbladder position and, 2:74, 2:95  
 large intestine and, 2:125  
 organ placement affected by, 1:63  
 stomach and, 2:121  
 types of, 1:531  
   asthenic, 1:63-65, 1:64t  
   hypersthenic, 1:63-65, 1:64t  
   hyposthenic, 1:63-64, 1:64t  
   sthenic, 1:63-64, 1:64t
- Body movement, 1:86-87**
- Body planes**  
 classification of  
   coronal, 1:58-1:59  
   horizontal, 1:58-1:59  
   interiliac, 1:60  
   oblique, 1:59  
   occlusal, 1:60  
   sagittal, 1:58-1:59  
 illustration of, 1:58  
 uses of, 1:59
- Body position**  
 decubitus, 1:84  
 definition of, 1:79  
 Fowler's, 1:80-1:81  
 lateral, 1:81  
 lordotic, 1:84  
 oblique  
   description of, 1:82  
   left anterior, 1:82  
   right anterior, 1:82  
 prone, 1:80  
 recumbent, 1:80  
 seated, 1:80  
 supine, 1:80  
 Trendelenburg's, 1:80-1:81  
 upright, 1:76, 1:80
- Body rotation method, for sternoclavicular articulations, 1:509**
- Bolus, 3:352**
- Bone**  
 anatomy of  
   general features, 1:66-1:67  
   nerves, 1:68  
   vessels, 1:68  
 classification of  
   flat, 1:69  
   illustration of, 1:69  
   irregular, 1:69  
   long, 1:68  
   sesamoid, 1:70  
   short, 1:68  
 cortical, 3:491  
 fractures  
   classification of, 1:74  
   closed, 1:74  
   displaced, 1:74  
   nondisplaced, 1:74  
   open, 1:74  
 functions of, 1:66  
 markings and features of  
   depressions, 1:74  
   processes, 1:74  
   projections, 1:74  
 ossification of  
   enchondral, 1:68  
   intermembranous, 1:68  
 remodeling of, 3:491-493, 3:528  
 resorption of, 3:492  
 trabecular, 3:491
- Bone cyst, 1:99, 1:242**
- Bone densitometry**  
 definition of, 3:528  
 dual x-ray absorptiometry  
   accuracy of, 3:504-506  
   clinical uses  
     body composition measurements, 3:524  
     forearm, 3:521-522  
     lumbar spine, 3:516-518  
     proximal femur, 3:519-520  
     skeletal measurements, 3:522-527  
   computer competency for, 3:512  
   description of, 3:484, 3:489  
   detectors, 3:501-502  
   fan-beam system, 3:502-503  
   fracture risk, 3:507  
   longitudinal quality control, 3:512-513  
   patient care, 3:510  
   patient history, 3:510  
   pencil-beam system, 3:501-503  
   physical principles of, 3:498-500  
   precision of, 3:504-506  
   radiation amounts, 3:508-3:508t  
   radiation protection, 3:508-509  
   record keeping for, 3:511  
   reference populations for, 3:507  
   T-scores, 3:507  
   Z-scores, 3:507



- Bone densitometry---*cont'd*  
 history of, 3:489-490  
 principles of, 3:488-489
- Bone marrow, 1:48t
- Bone mass, 3:493, 3:528
- Bone Mass Measurement Act, 3:511
- Bone mineral content, 3:499, 3:528
- Bone mineral density, 3:484, 3:489, 3:499-500, 3:507, 3:514, 3:528
- Bone scintigraphy, 3:183, 3:478
- Bony labyrinth, 2:289
- Bony thorax  
 anatomy of, 1:489, 1:495  
 functions of, 1:489  
 joints of, 1:491t
- Bowel obstruction, 2:76
- Boxer's fracture, 1:99
- Brachiocephalic artery, 3:143
- Brachiocephalic vein, 3:149
- Brachytherapy, 3:561, 3:575
- Bradyarrhythmia, 3:127
- Brain  
 anatomy of, 3:2  
 imaging of  
 computed tomography, 3:10-11  
 magnetic resonance imaging, 3:402  
 vasculature of, 3:50  
 ventricular system of, 3:4
- Breast  
 anatomy of, 2:465-466  
 augmented  
 magnetic resonance imaging of, 2:481  
 mammography of  
 breast cancer detection rate decreases, 2:480  
 craniocaudal projection  
 with full implant, 2:482-483  
 with implant displaced, 2:484-485  
 Eklund technique, 2:481  
 mediolateral oblique projection  
 with full implant, 2:486  
 with implant displaced, 2:487  
 sonography of, 2:481  
 diagnostic ultrasound, 3:434  
 lymphatic drainage, 2:466  
 male breast disease, 2:488  
 milk ducts of, 2:528  
 mobility of, 2:466  
 projections of, 2:460t  
 radiologic considerations, 2:466  
 tissue variations of, 2:467-468
- Breast cancer  
 diagnostic modalities  
 diaphanography, 2:529  
 thermography, 2:529  
 incidence of, 2:461  
 management principles for, 2:461  
 in men, 2:488  
 radiation therapy for, 3:572  
 risk factors, 2:464
- Breast Cancer Detection Demonstration Project, 2:462
- Breathing  
 expiration, 1:37  
 imaging considerations, 1:542  
 inspiration, 1:37
- Broden method, for subtalar joint, 1:285-287
- Bronchi, 1:532
- Bronchiectasis, 1:538
- Bronchitis, 1:538
- Bronchography, 1:536
- Bucket fracture, 3:185
- Buckle fracture, 1:99
- Buetti method, for atlanto-occipital articulations, 1:411
- Bunny method, for immobilization, 3:196-197  
 modified, 3:207
- Burman method, for AP projection of first carpometacarpal joint, 1:110-111
- Bursae, 1:72  
 definition of, 1:164  
 of humerus, 1:164
- Bursitis, 1:99, 1:168
- Butterfly set, 2:243
- Byte, 3:553
- C**
- Cahoon method, for styloid process imaging, 2:452-453
- Calcaneus  
 anatomy of, 1:231  
 projections for  
 axial, 1:279-281  
 chart, 1:243  
 dorsoplantar position, 1:280-281  
 lateral, 1:282  
 lateromedial oblique, 1:283  
 mediolateral, 1:282  
 overview, 1:228t  
 plantodorsal position, 1:279  
 radiologic imaging of, 1:266  
 weight-bearing coalition method, 1:281  
 weight-bearing method, 1:283
- Calculus, 2:42, 2:200
- Caldwell method  
 for cranial imaging, 2:308-311  
 for facial profile, 2:366-367  
 for frontal and anterior ethmoidal sinuses, 2:412-413
- Calyces  
 description of, 2:195  
 major, 2:197  
 minor, 2:197
- Camp-Coventry method, for intercondylar fossa, 1:322-323
- Canadian Association of Medical Radiation Technologists ethics, 1:3, 1:75
- Cancer  
 breast  
 diagnostic modalities  
 diaphanography, 2:529  
 thermography, 2:529  
 incidence of, 2:461  
 management principles for, 2:461  
 in men, 2:488  
 radiation therapy for, 3:572  
 risk factors, 2:464  
 cervical, 3:572  
 common types of, 3:558  
 definition of, 3:575  
 description of, 3:557  
 familial research, 3:559  
 incidence of, 3:557  
 larynx, 3:573  
 lung, 3:571  
 metastasis of, 3:557  
 oral cavity, 3:572  
 prostate, 3:571  
 recurrence of, 3:556  
 risk factors  
 carcinogens, 3:558-3:558t  
 external, 3:558  
 familial adenomatous polyposis, 3:559  
 hereditary nonpolyposis colorectal cancer, 3:559  
 internal, 3:558  
 skin, 3:573  
 tissue origins of, 3:559  
 TNM classification system, 3:559-3:559t
- Cancericidal dose, 3:575
- Cannulated hip screws, 3:282-284
- Capillary, 3:127
- Capitate  
 anatomy of, 1:92  
 projections of  
 AP, 1:123  
 PA, 1:122
- Capitulum, 1:94, 1:145
- Carcinogen, 3:575
- Carcinoma, 2:127, 3:559, 3:575
- Cardiac antrum, 2:119
- Cardiac catheterization  
 catheter introduction, 3:104  
 contraindications, 3:94  
 contrast media, 3:98-99  
 data collection, 3:106  
 definition of, 3:91  
 diagnostic uses  
 conduction system  
 in adults, 3:114  
 in children, 3:114  
 description of, 3:91  
 vascular system  
 in adults, 3:107-112  
 in children, 3:112  
 coronary arteries, 3:111-3:112t  
 equipment for  
 ancillary, 3:102-103  
 catheters, 3:98  
 cineangiography, 3:100  
 contrast media, 3:98-99  
 digital angiography, 3:100-101  
 guidewires, 3:96  
 introducer sheaths, 3:97  
 needles, 3:95  
 physiologic monitoring, 3:102  
 pressure injector, 3:99  
 supplies, 3:102  
 videotape image recording, 3:100  
 historical development of, 3:91  
 indications, 3:92-93  
 interventional uses  
 conduction system  
 in adults, 3:123-124  
 in children, 3:123-124  
 vascular system  
 in adults, 3:115-121  
 in children, 3:122  
 patient positioning, 3:104  
 postcatheterization care, 3:125  
 precatheterization care, 3:104  
 principles of, 3:92-94  
 risks associated with, 3:94  
 trends in, 3:125-126
- Cardiac cycle, 3:22
- Cardiac notch, 1:534, 2:120
- Cardiac output, 3:127
- Cardiomyopathies, 3:127
- Cardiovascular disease, 3:227
- Carina, 1:532
- Carotid artery  
 common, 3:137  
 anatomy of, 3:50-51  
 sectional anatomy of, 3:137, 3:143  
 internal, 3:141  
 magnetic resonance imaging of, 3:410
- Carotid sulcus, 2:283
- Carpal bones  
 anatomy of, 1:91-92  
 articulations of, 1:96  
 terminology associated with, 1:91t  
 types of, 1:91-92
- Carpal boss, 1:125
- Carpal bridge, 1:135
- Carpal canal  
 chart of projections for, 1:98  
 tangential projections of, 1:136-137
- Carpal interspaces, 1:123

- Carpal sulcus, 1:92
  - Carpal tunnel, 1:92
  - Carpometacarpal joint
    - anatomy of, 1:96
    - first
      - AP projection
        - Burman method, 1:110-111
        - Robert method, 1:108-109
      - PA projection, 1:106
- Cartilage
  - articular, 1:396
  - costal, 1:490
  - thyroid, 2:52, 3:138
- Cartilaginous joints
  - description of, 1:71
  - symphysis, 1:71
  - synchondrosis, 1:71
- Cartilaginous symphysis, 1:406
- Cassettes
  - for computed radiography
    - open, 1:34
    - split, 1:34
  - with film, 1:3
  - with imaging plate, 1:3-4
  - with phosphor plate, 1:3
- Catheterization, cardiac
  - catheter introduction, 3:104
  - contraindications, 3:94
  - data collection, 3:106
  - definition of, 3:30, 3:91
  - diagnostic uses
    - conduction system
      - in adults, 3:114
      - in children, 3:114
    - description of, 3:91
    - vascular system
      - in adults, 3:107-112
      - in children, 3:112
  - equipment for
    - ancillary, 3:102-103
    - catheters, 3:98
    - cineangiography, 3:100
    - digital angiography, 3:100-101
    - physiologic monitoring, 3:102
    - pressure injector, 3:99
    - supplies, 3:102
    - videotape image recording, 3:100
  - historical development of, 3:91
  - indications, 3:92-93
  - interventional uses
    - conduction system
      - in adults, 3:123-124
      - in children, 3:123-124
    - vascular system
      - in adults, 3:115-121
      - in children, 3:122
    - patient positioning, 3:104
    - postcatheterization care, 3:125
    - precatheterization care, 3:104
    - principles of, 3:92-94
    - risks associated with, 3:94
    - Seldinger technique, 3:30-31
    - trends in, 3:125-126
- Catheters, 3:32
- Cathode ray tube, 3:352, 3:370
- Caudad, 1:75
- Cauda equina, 3:3, 3:155, 3:164
- Caudate nucleus, 3:134, 3:140
- Causton method, for tangential projection of
  - sesamoid bones, 1:254-255
- Cavography
  - inferior vena cava, 3:44
  - superior vena cava, 3:43
- Cecum
  - anatomy of, 2:124
  - sectional anatomy of, 3:158-159
- Celiac artery, 3:38
- Celiac sprue, 2:127
- Celiac trunk, 3:152-153
- Centers for Disease Control and Prevention blood
  - and body fluid handling guidelines, 1:15-1:16t
- Central, 1:75
- Central nervous system
  - aging-related changes, 3:226
  - brain, *see* Brain
  - computed tomography of
    - brain, 3:10-11
    - contrast media use, 3:10
    - history of, 3:10
    - myelography, 3:11
    - single photon, 3:15
    - spinal cord, 3:11
  - diskography of, 3:14
  - interventional radiology of, 3:14
  - magnetic resonance angiography of, 3:16
  - myelography of
    - computed tomography, 3:11
    - contrast media for, 3:6-7
    - definition of, 3:6
    - examining room for, 3:7
    - patient positioning, 3:8
    - procedure, 3:8-9
  - nuclear medicine, 3:480
  - nucleography of, 3:14
  - positron emission tomography of, 3:15-16
  - radiography of, plain radiographic examination, 3:5
  - spinal cord
    - anatomy of, 3:3
    - transverse section of, 3:3
  - stereotactic surgery of, 3:16
  - stereotopic surgery of, 3:16
- Central ray
  - definition of, 1:29
  - direction of, 1:29
- Central ray angulation method, for sternoclavicular
  - articulations, 1:510-511
- Cephalad, 1:75
- Cephalometry
  - definition of, 2:264
  - description of, 2:264
- Cerebellum, 3:136
  - anatomy of, 3:2
  - sectional anatomy of, 3:139, 3:141
- Cerebral angiography
  - anatomic considerations, 3:50-52
  - anterior circulation, projections of
    - AP axial, 3:60-63
    - AP axial oblique, 3:61-62
    - lateral projection, 3:59
  - aortic arch angiogram, 3:58
  - circulation time, 3:54
  - definition of, 3:127
  - equipment, 3:55
  - examining room preparation, 3:56
  - imaging program for, 3:54
  - patient preparation, 3:55
  - positioning for, 3:56-57
  - posterior circulation, projections of
    - AP axial, 3:65
    - lateral, 3:64
    - submentovertical, 3:66-67
  - radiation protection, 3:56
  - technique, 3:53
- Cerebral aqueduct, 3:139
- Cerebral hemispheres, 3:133
- Cerebrovascular accident, 2:7t
- Cerebrum, 3:2
- Cerrobend blocks, 3:565, 3:575
- Certified surgical technologist, 3:267, 3:271
- Cervical cancer, 3:572
- Cervical intervertebral foramina
  - description of, 1:399
  - projections of
    - AP axial oblique, 1:426-427
    - chart, 1:409
    - oblique hyperflexion-extension, 1:427
    - overview, 1:392t
    - PA axial oblique, 1:428-429
    - in RAO and LAO positions, 1:428-429
    - in RPO and LPO positions, 1:426-427
- Cervical vertebrae
  - anatomy of, 1:394, 1:397-398
  - sectional, 3:137-138
  - curvature of, 1:395
  - entrance skin exposure for, 1:48t
  - Grandy method, 1:422-423
  - landmarks of, 1:62t
  - magnetic resonance imaging of, 3:404
  - mobile radiography projections of, 3:256-257, 3:296-297
  - operative radiology of, 3:279, 3:296-297
  - Ottonello method, 1:430-431
  - projections of
    - AP, 1:430-431
    - AP axial, 1:420-421
    - chart, 1:409
    - in hyperextension, 1:424
    - in hyperflexion, 1:424
    - lateral, 1:422-425
    - oblique, 1:486
    - overview, 1:392t
    - in right or left position, 1:422-425
  - sectional anatomy of, 3:137-138
  - surgical radiology of, 3:279
  - tomography of, 3:320t
  - trauma imaging
    - AP axial oblique projection, 2:14
    - AP axial projection, 2:13
    - dorsal decubitus, 2:11-12
    - lateral projection, 2:11-12
    - typical, 1:398-399
- Cervicothoracic region
  - Pawlow method, 1:438-439
  - projections of
    - chart, 1:409
    - lateral, 1:436-439
    - overview, 1:392t
    - in recumbent position, 1:438-439
    - in right or left position, 1:436-439
    - in upright position, 1:436-437
  - Twining method, 1:436-437
- Cervix
  - anatomy of, 2:254
  - cancer of, 3:572
- Chamberlain method, for abnormal sacroiliac
  - motion of symphysis pubis, 1:468-469
- Chassard-Lapiné method
  - for bladder and ureters imaging, 2:228
  - for large intestine axial projection, 2:189
  - for pelvis and upper femora imaging, 1:360-361
- Chaussé II method, for jugular foramina, 2:426
- Chest
  - anteroposterior view of, 1:9
  - arteries of, 3:50
  - entrance skin exposure for, 1:48t
  - mobile radiography projections
    - AP, 3:242-245
    - in neonate
      - AP, 3:258-261
      - lateral, 3:262-263
    - in right or left dorsal decubitus position, 3:262-263
    - PA, 3:244-245
    - in right or left lateral decubitus position, 3:244-245
    - in upright or supine position, 3:242-243
  - operative fluoroscopy of, 3:278

- Chest—*cont'd*  
 posteroanterior view of, 1:9  
 projections of  
   AP, 1:564-565  
   AP oblique, 1:562-563  
   chart, 1:539  
   lateral, 1:540-541, 1:543, 1:554-557  
   oblique, 1:540-541  
   overview, 1:530t  
   PA, 1:540-543, 1:550-553, 1:565  
   PA oblique, 1:558-561  
   in RAO and LAO positions, 1:558-561  
   in right or left position, 1:554-557  
   in RPO or LPO positions, 1:562-563  
 tomography of, 3:321t  
 trauma radiographs of, 2:16-17
- Children  
 abuse of  
   bone scintigraphy findings, 3:183  
   computed tomography findings, 3:183  
   description of, 3:180  
   fractures, 3:182, 3:184  
   suspected cases of  
     description of, 3:180-181  
     imaging guidelines, 3:184  
     radiographer's role, 3:184  
 cardiac catheterization  
   conduction system, 3:114, 3:123-124  
   vascular system, 3:112, 3:122  
 conduction system of, 3:114, 3:123-124  
 contrast arthrography for, 1:590  
 dose limits, 1:46  
 vascular system of, 3:112, 3:122
- Chloral hydrate, 2:240t-241t
- Cholangiography  
 intravenous, 2:108-109, 3:316-317  
 operative, 3:276-277  
 percutaneous transhepatic, 2:110-111  
 postoperative, 2:112-113
- Cholecystitis, 2:76
- Cholecystography, oral  
 contraindications, 2:96  
 contrast media for, 2:91-93, 2:97  
 development of, 2:91  
 fatty meal, 2:100  
 indications, 2:96  
 intestinal tract preparation, 2:96-97  
 intravenous, 2:92  
 opacified gallbladder, 2:99-100  
 patient instructions, 2:96, 2:98  
 postprocedure instructions, 2:100  
 preliminary diet, 2:96  
 scout radiographs  
   description of, 2:98  
   inspection of, 2:99
- Cholecystokinin, 2:74
- Choledocholithiasis, 2:76
- Chondrosarcoma, 1:99, 1:168, 1:242, 1:353, 1:496
- Chorion, 2:255
- Chromium, 3:467t
- Chromosome, 3:575
- Chronic obstructive pulmonary disease, 1:538
- Cineangiography, 3:127
- Cinefluorography, 3:127
- Circle of Willis, 3:52, 3:136
- Circulation  
 anterior, cerebral angiography of  
   AP axial, 3:60-63  
   AP axial oblique, 3:61-62  
   lateral projection, 3:59  
 portal, 3:22, 3:81, 3:128  
 posterior, cerebral angiography of  
   AP axial, 3:65  
   lateral, 3:64  
   submentovertical, 3:66-67  
 pulmonary, 3:21, 3:23, 3:128
- Circulation—*cont'd*  
 systemic, 3:21, 3:23, 3:128  
 velocity of, 3:24
- Circulatory system  
 anatomy of, 3:20  
 arteries, *see* Arteries  
 veins, *see* Veins
- Circumduction, 1:87
- Cisterna chyli, 3:24
- Cisternae, 3:3
- Claudication, 3:49, 3:127
- Clavicle  
 anatomy of, 1:161  
   sectional, 3:149  
 projections for  
   AP, 1:205  
   AP axial, 1:207  
   chart for, 1:168  
   in lordotic position, 1:207  
   overview, 1:160t  
   PA, 1:206  
   PA axial, 1:208  
   tangential, 1:208-211  
   sectional anatomy of, 3:149  
   Tarrant method for, 1:210-211
- Clavicular notch, 1:490
- Clay shoveler's fracture, 1:408
- Cleaves method  
 for axial projection of shoulder joint, 1:169  
 for femoral neck, 1:362-365
- Clements modification, for inferosuperior axial  
 projection of shoulder girdle, 1:180-181
- Clements-Nakayama method  
 for hip imaging, 1:372-373  
 for trapezium imaging, 1:134
- Clinical history, 1:13
- Clivus, 2:283, 2:285, 3:136
- Clubfoot  
 definition of, 1:242, 3:185  
 Kandel method, 1:278  
 Kite method, 1:275-277  
 projections of  
   AP, 1:275  
   axial, 1:278  
   dorsoplantar position, 1:278  
   lateral, 1:276-277
- CM line, 3:553
- Coagulopathy, 3:127
- Coalition position, for calcaneus, 1:281
- Coal miner's lung, 1:538
- Cobalt, 3:467t
- Cobalt-60 units, 3:562
- Coccygeal cornua, 1:405
- Coccygeal vertebrae, 1:394
- Coccyx  
 anatomy of, 1:405  
 projections of  
   AP axial, 1:470-471  
   chart, 1:409  
   lateral, 1:472-473  
   overview, 1:393t  
   PA axial, 1:470-471  
   in right or left position, 1:472-473  
   sectional anatomy of, 3:164
- Cochlea, 2:289
- Coil, 3:413
- Colcher-Sussman method, for pelvimetry, 2:267
- Cold spot, 3:485
- Colitis, 2:127
- Collateral, 3:127
- Colle's fracture, 1:99
- Collimation  
 for computed radiography, 1:34  
 definition of, 1:50  
 for patient protection, 1:50  
 of x-ray beam, 1:30, 1:50
- Collimator, 3:485, 3:575
- Colon  
 anatomy of, 2:125  
 ascending, 2:125  
 descending, 2:125  
 preparation of, 1:18  
 projections of  
   AP, 2:180  
   AP axial, 2:181  
   AP oblique, 2:182-183  
   PA oblique, 2:178  
 sigmoid, 2:125  
 transverse, 2:125
- Colonic fistula, 2:90
- Color flow Doppler, 3:458
- Colostomy  
 diagnostic enema, 2:190  
 equipment, 2:190  
 intestinal tract preparation, 2:190  
 patient preparation, 2:190  
 spot radiographs, 2:190-2:191
- Common bile duct, 2:73
- Common carotid artery  
 anatomy of, 3:50-51  
 sectional anatomy of, 3:137, 3:143
- Common hepatic duct, 2:73
- Common iliac vein, 3:158-159
- Compact bone, 1:66
- Compare feature, 3:528
- Compression fracture, 1:408
- Computed radiography  
 abdomen, 2:89  
 acromioclavicular articulations, 1:201  
 analog, 3:356  
 benefits of  
   department efficiency, 3:369  
   diagnostic accuracy, 3:367  
   picture archive and communication system, 3:367-370, 3:377, 3:383  
   repeat rate reduction, 3:367  
   telerradiographic transmission, 3:367  
   x-ray dosage reduction, 3:367  
 cervicothoracic region, 1:437-438  
 clavicle, 1:205-206  
 clinical acceptance, 3:366  
 clinical applications of, 3:362-365  
 CRT monitors, 3:359-360  
 definition of, 3:370  
 diagnostic efficacy of, 3:365  
 display functions, 3:359-360  
 hip, 1:371  
 historical development of, 3:357  
 image acquisition functions, 3:357-359  
 image characteristics, 3:361  
 leg, 1:302-303, 1:307  
 lungs, 1:574  
 patella, 1:327, 1:335  
 pitfalls associated with, 3:366  
 pleurae, 1:574  
 principles of, 1:33, 3:356  
 pulmonary apices, 1:567  
 quality assurance, 3:366  
 scapula, 1:214  
 scapular Y projection of shoulder joint, 1:185  
 second through fifth digits, 1:101  
 shoulder girdle  
   with externally rotated humerus, 1:172  
   with internally rotated humerus, 1:172  
   with neutrally rotated humerus, 1:172  
 sternum, 1:504-505, 1:507  
 storage functions, 3:360-361  
 technical considerations  
   cassettes  
     open, 1:34  
     split, 1:34  
   collimation, 1:34  
   grids, 1:34



- Computed radiography—*cont'd*  
 technical considerations—*cont'd*  
   image reader, 1:33  
   kilovoltage, 1:34  
   overexposure, 1:34  
   part centering, 1:34  
   underexposure, 1:34  
 thoracic vertebrae, 1:443
- Computed tomography  
 angiography, 3:346-347  
 brain, 3:10-11  
 child abuse, 3:183  
 contrast arthrography and, 1:593  
 contrast media for, 3:10, 3:342  
 conventional radiography and, 3:330-331  
 definition of, 3:352  
 diagnostic applications, 3:340-341  
 dynamic scanning, 3:344  
 factors affecting image quality  
   artifacts, 3:343  
   contrast resolution, 3:343  
   noise, 3:343  
   patient, 3:343  
   scan diameter, 3:344  
   scan times, 3:344  
   spatial resolution, 3:342  
 frontal sinus, 2:404-405  
 fundamentals of, 3:330  
 future of, 3:352  
 historical development of, 3:333-335  
 history of, 3:10  
 for limb length measurements, 1:582  
 magnetic resonance imaging and, comparison  
   between, 3:351  
 myelography, 3:11  
 pediatric use, 3:212-213  
 pelvis, 1:359  
 peripheral quantitative, 3:526, 3:529  
 positron emission tomography and, comparison  
   between, 3:532-534, 3:533t  
 quality control, 3:350  
 quantitative, 3:489, 3:522  
 radiation treatment planning, 3:350  
 single photon, 3:15  
 spinal cord, 3:11  
 spiral/helical, 3:345-346  
 stereotactic localization and, 3:17  
 system components  
   computer, 3:336  
   display monitor, 3:338-339  
   gantry, 3:336-337  
   multiplanar reconstruction unit, 3:340  
   operator's console, 3:338  
   table, 3:337  
 technical aspects of, 3:335  
 three-dimensional imaging  
   description of, 3:348  
   maximum intensity projection, 3:348  
   shaded surface display, 3:349  
   volume rendering, 3:349
- Concha, 2:289  
 Condylar canals, 2:285  
 Condylar process, 2:292  
 Condyle, 1:74  
 Cones, 2:343  
 Conformal radiation, 3:575  
 Conjunctiva, 2:342, 2:348  
 Conjunctival sac, 2:348  
 Contamination, 3:303  
 Continuous wave ultrasound, 3:458  
 Contour, 3:575  
 Contralateral, 1:75  
 Contrast  
   definition of, 1:4  
   illustration of, 1:6
- Contrast arthrography  
 anesthetic for, 1:585  
 computed tomography and, concomitant use of,  
   1:593  
 description of, 1:584  
 hip  
   in adults, 1:590-591  
   in children, 1:590  
   dislocations, 1:585  
   indications, 1:590  
   subtraction technique, 1:590-591  
 knee  
   double-contrast arthrography, 1:588-589  
   using vertical ray method, 1:586-587  
 pneumoarthrography, 1:585  
 shoulder, 1:592-593  
 temporomandibular joint, 1:594-595  
 wrist, 1:590
- Contrast media  
 administration routes, 2:92-93  
 barium sulfate  
   for alimentary canal evaluations, 2:128-129  
   cardiac studies using, 1:553, 1:557, 1:561  
   description of, 2:128  
   diagnostic uses  
     alimentary canal, 2:128-129  
     esophagus, 2:133-134  
     gastrointestinal series, 2:138  
     small intestine, 2:157  
     stomach, 2:138  
   for enteroclysis, 2:161  
   for biliary tract imaging, 2:92-93  
   for cardiac catheterization, 3:98-99  
   for cholecystography, 2:91t, 2:97  
   for computed tomography, 3:342  
   elderly considerations, 3:230  
   for endoscopic retrograde  
     cholangiopancreatography, 2:114  
   for esophagus  
     barium sulfate mixture  
       administration of, 2:138  
       description of, 2:133-134  
     double-contrast, 2:135  
     opaque foreign bodies, 2:135  
     overview, 2:133  
     procedure, 2:134-135  
     single-contrast, 2:133-134  
   for hysterosalpingography, 2:260-261  
   iodinated solutions, 2:130  
   for magnetic resonance imaging, 3:400-401  
   for positive-contrast laryngopharyngography,  
     2:60-61  
   for postoperative cholangiography, 2:112-113  
   for sialography, 2:43  
   for thoracic aortography, 3:33  
   for vaginography, 2:260  
   water-soluble, 2:129
- Contrast resolution, 3:352  
 Contre-coup fracture, 2:296  
 Cooper's ligaments, 2:465  
 Coracoid process  
   definition of, 1:74  
   projections for, 1:215  
     AP axial, 1:220-221  
     overview, 1:160t
- Cornea, 2:343  
 Coronal image plane, 3:458  
 Coronal plane, 1:58-1:59  
 Corona radiata, 3:133  
 Coronoid fossa, 1:94  
 Coronoid process, 1:144, 2:292  
 Corpora cavernosa, 3:164  
 Corpus callosum, 3:2, 3:134, 3:139-141  
 Corpus cavernosa, 3:160-161  
 Corpus spongiosum, 3:164  
 Cortex, 2:253, 3:133
- Cortical bone, 3:528  
 Cosmic radiation, 1:44  
 Costal cartilage, 1:490  
 Costal facets, 1:400-1:401t  
 Costal groove, 1:490  
 Costal joints  
   AP axial projection of, 1:526-527  
   overview, 1:488t
- Costochondral articulations, 1:492  
 Costophrenic angle, 1:534  
 Costotransverse joint, 1:491t  
 Costovertebral joints, 1:406, 1:491t
- Cranial bones  
 ethmoid bone, 2:280  
 frontal bone, 2:279  
 occipital bone, 2:284-285  
 parietal bones, 2:281  
 sphenoid bone, 2:282-284  
 temporal bones, 2:286
- Cranial nerves, 3:141
- Cranium  
 anatomy of, 2:275-277  
   sectional, 3:132-141, 3:166  
 base  
   chart of projections, 2:297  
   Schüller method, 2:322-323  
   submentovertex projection of, 2:322-323  
   verticosubmental projection of, 2:325  
 bedside examinations of, 2:311  
 Caldwell method, 2:308-311  
 development of, 2:278  
 floor of, 2:278  
 Haas method, 2:320-321  
 magnetic resonance imaging of, 2:277  
 projections of  
   AP axial, 2:297, 2:312-319  
   chart, 2:297  
   in dorsal decubitus position, 2:306-307  
   lateral, 2:297, 2:304-307  
   in lateral decubitus position, 2:311, 2:318-319  
   overview, 2:274t  
   PA axial, 2:297, 2:302, 2:308-311, 2:320-321  
   in right or left position, 2:304-307  
   scout, 2:33  
   in supine lateral position, 2:306-307  
 scout images of, 2:33  
 sectional anatomy of, 3:132-141, 3:166  
 shape of, 2:278  
 stretcher examination of, 2:311  
 Towne method, 2:24-25, 2:314-319  
 trauma radiographs of  
   AP axial projection, 2:24-25  
   AP projection, 2:24-25  
   dorsal decubitus position, 2:22-23  
   lateral projection, 2:22-23  
   Towne method, 2:24-25  
   Valdini method, 2:302
- Crest, 1:74  
 Cribriform plate, 2:280  
 Crista galli, 2:280  
 Crohn's disease, 2:127  
 Cross-sectional image, 3:458  
 Cryogenic, 3:413  
 Cuboid, 1:231  
 Cuneiforms  
   anatomy of, 1:231  
   radiologic imaging of, 1:274
- Cure, 3:575  
 Curie, 3:466, 3:485  
 Cyclotron, 3:485  
   definition of, 3:553  
   description of, 3:538-539  
   positive-ion, 3:539  
   proton-only, 3:539
- Cystic duct, 2:73  
 Cystic fibrosis, 1:538, 3:185

- Cystitis, 2:200
- Cystography  
 contraindications, 2:228  
 contrast media for  
 description of, 2:228  
 injection of, 2:228  
 definition of, 2:205  
 indications, 2:228  
 injection equipment, 2:228  
 preliminary preparations, 2:228  
 retrograde, 2:228-233  
 trauma uses, 2:34
- Cystoureterography  
 definition of, 2:205, 2:228  
 female, 2:236-238  
 male, 2:201, 2:235  
 metallic bead chain, 2:236-238
- Cystourethrography, 2:194t
- D**
- Dacryocystography, 2:348-349
- Danielius-Miller method, for hip, 1:370-372
- Data acquisition system, 3:336
- Daughter, 3:485
- Deadtime, 3:553
- Decay, 3:485, 3:575
- Decubitus position  
 description of, 1:84  
 dorsal, 1:84  
 lateral, 1:84  
 ventral, 1:84
- Deep, 1:75
- Default, 3:370
- Defecography, 2:192
- Deglutition, 2:56-57
- Dementia, 3:224
- Demerol. *see* Meperidine hydrochloride
- Demifacet, 1:400
- Dens  
 anatomy of, 1:397  
 atlas and, PA projection of, 1:416  
 Fuchs method, 1:413  
 Judd method for, 1:416  
 Kasabach method, 1:417  
 projections of  
 AP, 1:413  
 AP axial, 1:417  
 chart, 1:409  
 overview, 1:392t  
 in right or left head positions, 1:417  
 sectional anatomy of, 3:141  
 Smith and Abel method, 1:413
- Densitometry, bone  
 definition of, 3:528  
 dual x-ray absorptiometry  
 accuracy of, 3:504-506  
 clinical uses  
 body composition measurements, 3:524  
 forearm, 3:521-522  
 lumbar spine, 3:516-518  
 proximal femur, 3:519-520  
 skeletal measurements, 3:522-527  
 computer competency for, 3:512  
 description of, 3:484, 3:489  
 detectors, 3:501-502  
 fan-beam system, 3:502-503  
 fracture risk, 3:507  
 longitudinal quality control, 3:512-513  
 patient care, 3:510  
 patient history, 3:510  
 pencil-beam system, 3:501-503  
 physical principles of, 3:498-500  
 precision of, 3:504-506  
 radiation amounts, 3:508-3:508t  
 radiation protection, 3:508-509  
 record keeping for, 3:511
- Densitometry, bone—*cont'd*  
 dual x-ray absorptiometry—*cont'd*  
 reference populations for, 3:507  
 T-scores, 3:507  
 Z-scores, 3:507  
 history of, 3:489  
 principles of, 3:488-489
- Depressed fracture, 2:296
- Dermoid cyst, 2:259
- Descending aorta, 3:144-145
- Descending colon, 3:157-159
- Detectors  
 assembly, definition of, 3:352  
 definition of, 3:352, 3:553  
 radioactive  
 gas-filled, 3:469  
 scintillation, 3:469
- Deuteron, 3:553
- Deviation  
 radial, 1:129  
 ulnar, 1:128, 1:132-133
- Diagnostic ultrasound  
 advantages of, 3:416  
 anatomic relationships, 3:419  
 clinical applications of  
 abdomen, 3:419-422  
 cardiologic  
 cardiac pathology, 3:454-456  
 congenital heart lesions, 3:456  
 echocardiography, 3:452-453  
 myocardial infarction, 3:455  
 overview, 3:452  
 gallbladder, 3:426-427  
 gynecologic, 3:438-442  
 kidneys, 3:428-432  
 liver, 3:422-423  
 obstetric, 3:443-449  
 pancreas, 3:424-425  
 pelvis, 3:438-440  
 retroperitoneum, 3:419-437  
 spleen, 3:422  
 superficial structures, 3:434-435  
 testicles, 3:435  
 vascular, 3:450-451  
 color flow Doppler, 3:419  
 Doppler effect, 3:419  
 endovaginal, 3:440, 3:443  
 historical development of, 3:417  
 neonatal neurosonography, 3:436-437  
 physical principles of, 3:417-419  
 principles of, 3:416  
 real-time imaging, 3:419  
 resource organizations for, 3:416  
 sonographer for, 3:416  
 sound wave properties  
 acoustic impedance, 3:417  
 overview, 3:417  
 velocity, 3:418
- Diaphanography, 2:529
- Diaphragm  
 anatomy of, 1:494, 1:531  
 respiratory movement of, 1:494  
 rib imaging considerations, 1:520-521
- Diaphysis, 1:68
- Diastole, 3:127
- Diazepam, 2:240t-241t
- Differentiation, 3:575
- Diffusion, 3:411, 3:413
- Digestive system  
 aging-related changes, 3:227  
 anatomy of, 2:71, 2:75  
 components of, 2:71, 2:119
- Digit  
 anatomy of, 1:91  
 first  
 AP projection, 1:106  
 lateral projection, 1:106
- Digit—*cont'd*  
 first—*cont'd*  
 overview, 1:90t  
 PA oblique projection, 1:107  
 PA projection, 1:106  
 overview, 1:90t  
 second through fifth  
 lateral projections, 1:102-103  
 PA oblique projection, 1:104-105  
 PA projections for, 1:100-101
- Digital, 3:370, 3:383
- Digital disk, 3:383
- Digital spot imaging  
 clinical uses of, 3:382  
 description of, 3:376  
 principles of, 3:374
- Digital subtraction angiography  
 definition of, 3:383  
 equipment and apparatus for, 3:375-376  
 historical development, 3:374  
 image postprocessing  
 analytic tools, 3:379  
 contrast and brightness adjustment, 3:378  
 edge enhancement, 3:379  
 image zoom, 3:379  
 landmarking, 3:379  
 pixel shifting, 3:378  
 remasking, 3:378  
 unsubtracted images, 3:378  
 view tracing, 3:379  
 intraarterial, 3:380-381  
 intravenous, 3:381  
 intravenous versus intraarterial injection, 3:374  
 principles of, 3:374  
 procedure, 3:376-377  
 road mapping using, 3:381  
 system for, 3:375-376
- Digitize, 3:383
- Diphenhydramine hydrochloride, 2:240t-241t
- Diploë, 1:69, 2:277
- Direct coronal, 3:352
- Direct effect, 3:575
- Directional coronary atherectomy, 3:117, 3:127
- Disinfectants, 1:16
- Diskography, 3:15
- Dislocation, 1:99, 1:168, 1:242, 1:353
- Distal, 1:75
- Distal humerus projections, 1:90t
- Distal interphalangeal joint, 1:95, 1:238
- Distal tibiofibular joint, 1:240
- Diverticulitis, 2:127
- Diverticulosis, 2:127
- Diverticulum, 2:127
- Doppler effect, 3:419, 3:458
- Dorsum, 1:75
- Dorsum sellae, 2:283  
 projections of  
 AP axial, 2:328-329  
 PA axial, 2:330-331
- Dose  
 definition of, 3:553  
 fetal, 1:49  
 limits  
 for children, 1:46  
 for skin, 1:46  
 mean marrow, 1:48  
 organ, 1:48  
 patient  
 fetal dose, 1:49  
 organ dose, 1:48
- Dose equivalent  
 effective  
 definition of, 1:46  
 ICRP recommendations, 1:46  
 mathematical expression of, 1:46  
 for whole body, 1:46

- Dose-response relationship  
description of, 1:45  
schematic representation of, 1:45
- Dosimetry  
definition of, 3:567, 3:575  
for positron emission tomography, 3:550  
process of, 3:567-569  
in radiation oncology, 3:567-569  
thermoluminescent badges for, 1:54
- Dual energy imaging, definition of, 3:370
- Dual-energy x-ray absorptiometry, 3:485
- Dual photon absorptiometry, 3:490, 3:528
- Dual x-ray absorptiometry  
accuracy of, 3:504-506  
clinical uses  
body composition measurements, 3:524  
forearm, 3:521-522  
lumbar spine, 3:516-518  
proximal femur, 3:519-520  
skeletal measurements, 3:522-527  
computer competency for, 3:512  
definition of, 3:528  
description of, 3:484, 3:489  
detectors, 3:501-502  
fan-beam system, 3:502-503  
follow-up scans, 3:514  
fracture risk, 3:507  
longitudinal quality control, 3:512-513  
patient care, 3:510  
patient history, 3:510  
pencil-beam system, 3:501-503  
peripheral, 3:529  
physical principles of, 3:498-500  
precision of, 3:504-506  
radiation amounts, 3:508-3:508t  
radiation protection, 3:508-509  
record keeping for, 3:511  
reference populations for, 3:507  
T-scores, 3:507  
Z-scores, 3:507
- Ductus deferens  
anatomy of, 2:256  
sectional anatomy of, 3:165
- Dunlap, Swanson, and Penner method, for acetabulum, 1:352
- Duodenal bulb, 2:123
- Duodenography, hypotonic, 2:141
- Duodenojejunal flexure, 2:123
- Duodenum  
anatomy of, 2:123  
mucosal studies, 2:156  
projections of  
AP, 2:152-153  
AP oblique, 2:148-149  
chart, 2:126  
lateral, 2:150-151  
overview, 2:118t  
PA, 2:142-143  
PA axial, 2:144-145  
PA oblique, 2:146-147, 2:156  
in right position, 2:150-151
- Dural sac, 3:3
- Dura mater, 3:3
- Dynamic imaging, 3:458
- Dynamic range, 3:370
- Dynamic range control, 3:370
- Dynamic scanning, 3:352
- Dyspnea, 3:127
- E**
- Ear  
external, 2:289  
internal, 2:289  
middle, 2:289  
PA axial projection of, 2:302  
schematic representation of, 2:288  
Valdini method, 2:302
- Echo, 3:458
- Echocardiography, 3:452-453
- Echogenic, 3:458
- Echo planar imaging, 3:413
- Edge enhancement, 3:370, 3:383
- Edison, Thomas, 1:40
- Efferent arteriole, 2:197
- Efferent lymph vessel, 3:127
- Ejaculatory ducts, 2:256
- Ejection fraction, 3:108, 3:110, 3:127
- Elbow  
articulations of, 1:97  
projections for  
AP, 1:141  
AP oblique  
lateral rotation, 1:145  
medial rotation, 1:144  
chart for, 1:98  
lateral, 1:142-143  
overview, 1:90t
- Elderly. *see also* Aging; Geriatrics  
cognitive impairments in, 3:224  
communication with, 3:229  
conditions found in, 3:222  
contrast administration considerations, 3:230  
demographics, 3:220-223  
economic status, 3:221  
health care provider's attitudes toward, 3:220-223  
health complaints of, 3:224b  
JCAHO criteria, 3:231  
lifting of, 3:230  
patient education, 3:229  
skin care for, 3:230  
tips for working with, 3:229b  
transportation of, 3:230
- Electron, 3:485
- Electron capture, 3:463, 3:485
- Ellipsoid joint, 1:72-1:73
- Embolization, transcatheter, 3:73-75
- Embolus, 3:127
- Emphysema, 1:538
- Enchondroma, 1:99, 1:242
- Endocardium, 3:21, 3:127
- Endochondral ossification, 1:68
- Endometrial polyp, 2:259
- Endometrium, 2:254
- Endorectal transducer, 3:458
- Endoscopic retrograde cholangiopancreatography, 2:114-115
- Endosteum, 1:66
- Endovaginal transducer, 3:458
- Enema, for large intestine contrast studies, 2:165-166
- Energy subtraction, 3:365, 3:370
- English-Metric conversion system, 1:28
- Enteroclysis, 2:161
- Entrance skin exposure  
definition of, 1:47-1:47t  
measurement methods, 1:47
- Epicardium, 3:21, 3:127
- Epicondyle  
definition of, 1:74  
lateral  
anatomy of, 1:94, 1:234  
AP projection of, 1:139  
radiologic imaging of, 1:309  
medial  
anatomy of, 1:94, 1:234  
projection of  
AP, 1:139  
AP oblique, 1:144  
radiologic imaging of, 1:309
- Epididymis, 2:256
- Epididymography, 2:270
- Epidural space, 3:3
- Epiglottis  
anatomy of, 2:52  
imaging considerations for, 3:179  
sectional anatomy of, 3:149
- Epiglottitis, 1:538, 2:42
- Epiphyseal artery, 1:68
- Epiphyseal plate, 1:68-1:69
- Epiphysis, 1:68-1:69
- Epithelial tissue, 3:575
- Eraso modification, for jugular foramina, 2:454-455
- Erector spinae muscle, 3:155
- Ergometer, 3:127
- Esophageal varices, 2:127
- Esophagogastric junction, 2:119
- Esophagus  
anatomy of, 1:535, 2:119  
contrast studies  
barium sulfate mixture  
administration of, 2:138  
description of, 2:133-134  
double-contrast, 2:135  
opaque foreign bodies, 2:135  
overview, 2:133  
procedure, 2:134-135  
single-contrast, 2:133-134  
distal, PA oblique projection of, 2:154-155  
layers of, 2:119  
pharyngography of  
deglutition assessments using, 2:56-57  
description of, 2:56  
Gunson method, 2:57  
projections of  
AP, 2:126, 2:136-137  
AP oblique, 2:136  
chart, 2:126  
exposure time considerations, 2:132  
lateral, 2:126, 2:136-137  
overview, 2:118t  
PA, 2:126, 2:136-137  
PA oblique, 2:136-137  
in RAO or LPO position, 2:136-137  
in right or left position, 2:136  
sectional anatomy of, 3:143, 3:146-147, 3:151
- Ethics  
American Society of Radiologic Technologists, 1:2  
Canadian Association of Medical Radiation Technologists, 1:3  
definition of, 1:2
- Ethmoidal notch, 2:279
- Ethmoidal sinus  
anatomy of, 2:280, 2:404  
Caldwell method, 2:412-413  
open-mouth Waters method, 2:416-417  
projections of  
chart, 2:406  
PA, 2:420  
PA axial, 2:412-413  
parietoacanthial, 2:416-417  
submentovertical, 2:418-419  
technical considerations, 2:407-409  
sectional anatomy of, 3:136
- Ethmoid bone, 2:280
- Etiology, 3:575
- Eversion, 1:87
- Ewing's sarcoma, 1:99, 1:242, 3:185
- Excretory urography  
contrast media, 2:206  
history of, 2:206  
radiation protection during, 2:213  
ureteral compression during, 2:212
- Exocrine cells, of pancreas, 2:74
- Expiration  
description of, 1:37  
lung activity during, 1:534  
PA projection, 1:552



- Expiratory phonation tests, 2:58  
 Exposure, 1:43  
 Exposure technique  
   adaptation of, 1:36  
   body habitus and, 1:63  
   description of, 1:35  
   pathologic conditions that require adaptation of, 1:36  
 Exposure time setting, 1:37  
 Extension, 1:86  
 External, 1:75  
 External acoustic meatus, 2:283, 2:307, 2:357  
 External-beam therapy, 3:561, 3:575  
 External oblique muscle, 3:152-153  
 External occipital protuberance, 2:284  
 External radiation detector, 3:485  
 Extravasation, 3:127  
 Eye  
   anatomy of, 2:342-343  
   foreign body localization, 2:344  
   modified Waters method, 2:347  
   projections of  
     lateral, 2:345  
     overview, 2:274t  
     PA axial, 2:346  
     parietoacanthial, 2:347  
     in right or left position, 2:345
- F**
- Facet, 1:74  
 Facial bones  
   function of, 2:275  
   inferior nasal conchae, 2:291  
   lacrimal bones, 2:290  
   maxillary bones, 2:290  
   nasal bones, 2:290  
   palatine bones, 2:291  
   projections of  
     acanthioparietal, 2:26, 2:364-365  
     chart, 2:353  
     lateral, 2:355-357  
     overview, 2:352t  
     parietoacanthial, 2:360-361  
     in right or left position, 2:355-357  
   trauma of, 2:26, 2:364-365  
   vomer, 2:291  
   Waters method  
     modified, 2:362-363  
     reverse, 2:353, 2:364-365  
     standard, 2:353, 2:360-361  
   zygomatic bones, 2:291  
 Facial profile  
   Caldwell method, 2:366-367  
   lateral projection of, 2:358-359  
   PA axial projection of, 2:366-367  
 Falciform ligament, 2:72  
 "False profile" position, for acetabulum, 1:378  
 Falx cerebelli, 3:136  
 Falx cerebri, 3:133  
 Familial adenomatous polyposis, 3:559  
 Fan lateral position, for lateral projection of hand, 1:118-119  
 Fat pads  
   anatomy of, 1:97  
   illustration of, 1:97  
 Fat-suppressed images, 3:398  
 Feet. *see* Foot  
 Female reproductive system  
   ovaries, 2:253  
   radiography  
     hysterosalpingography, 2:260-261  
     intrauterine device localization, 2:269  
     for nonpregnant patients, 2:260-261  
     pelvic pneumography, 2:260, 2:262  
     vaginography, 2:260, 2:262-263  
     uterine tubes, 2:253  
     uterus, 2:254  
     vagina, 2:254
- Femoral artery, 3:160-161  
 Femoral vein, 3:160-161  
 Femur  
   anatomy of, 1:234-235, 1:346  
     sectional, 3:160-161  
   angulation of, 1:348  
   antegrade nailing of, 3:285  
   arteriography of, 3:294-295  
   articulations of, 1:234-235  
   mobile radiography projections of  
     AP, 3:252-253  
     lateral, 3:254-255  
     in mediolateral or lateromedial dorsal  
       decubitus position, 3:254-255  
   neck of  
     Cleaves method for, 1:362-365  
     projections of  
       AP oblique, 1:362-363  
       axiolateral, 1:364-365  
       bilateral, 1:362  
       chart, 1:353  
       unilateral, 1:362  
       radiologic imaging of, 1:367  
     projections for  
       AP, 1:336-337  
       chart, 1:243  
       lateral, 1:338-339  
       in mediolateral position, 1:338-339  
       overview, 1:229t  
     proximal  
       anatomy of, 1:347-348  
       dual x-ray absorptiometry of, 3:519-520  
       radiologic imaging of, 1:309  
       retrograde nailing of, 3:286  
       sectional anatomy of, 3:160-161  
   Femur nail, 3:285-287  
 Ferguson method, for scoliosis, 1:480-481  
 Feridex, 3:400  
 Fetal dose  
   description of, 1:49  
   during radiographic examinations, 1:49t  
 Fetography, 2:264  
 Fetus  
   development of, 2:255  
   diagnostic ultrasound of, 3:443-449  
   <sup>18</sup>F-2-Fluoro-2-deoxy-D-glucose, 3:541  
 Fibrillation, 3:127  
 Fibrous gomphoses, 2:293  
 Fibrous joints, 1:71  
 Fibula  
   anatomy of, 1:233  
   projections for  
     AP, 1:303  
     lateral, 1:304-305  
 Fibular collateral ligament, 1:236  
 Fibular notch, 1:233  
 Field, 3:575  
 Field of view, 3:352  
 Film badge, 1:54  
 Film changer, 3:127  
 Film sizes, 1:28-1:28t  
 Fimbriae, 2:253  
 Fisk modification, for AP axial projection of  
   humerus, 1:196  
 Fission, 3:486  
 Fissure, 1:74  
 Fistula, 2:42, 2:200, 2:259  
 Flat bones, 1:69  
 Fleischner method, for pulmonary apices, 1:536  
 Flexion, 1:86  
 Flexor retinaculum, 1:92  
 Flexor tendons, 1:92  
 Fluoroscopic screen, 1:3  
 Fluoroscopy  
   mobile, 2:3  
   pulsed, 3:188  
   radiographer exposure during, 1:52  
   stomach, 2:139
- Fluoroscopy—*cont'd*  
   tabletop output intensity, 1:47  
   trauma evaluations, 2:3  
 Focal plane, 3:327  
 Focus, 3:458  
 Folia, 3:2  
 Folio method, for first metacarpophalangeal joint, 1:112-113  
 Follow-up scans, 3:528  
 Fontanelles  
   anterior, 2:278  
   description of, 2:278  
   mastoid, 2:278  
   posterior, 2:278  
   sphenoidal, 2:278  
 Foot  
   anatomy of, 1:230-232  
   clubfoot deformity  
     Kandel method, 1:278  
     Kite method, 1:275-277  
     projections of  
       AP, 1:275  
       axial, 1:278  
       dorsoplantar position, 1:278  
       lateral, 1:276-277  
   Grashey method for, 1:264-265  
   longitudinal arch of, 1:270-271  
   projections for  
     AP, 1:256-259  
     AP axial, 1:256-259, 1:272-274  
     AP oblique, 1:260-263  
     chart, 1:243  
     lateral, 1:267-271  
     lateral rotation, 1:262-265  
     lateromedial, 1:267-271  
     medial rotation, 1:260-261, 1:264-266  
     overview, 1:228t  
     PA oblique, 1:264-266  
     weight-bearing composite method, 1:273-274  
     weight-bearing method, 1:270-272  
 Foramen, 1:74  
 Foramen lacerum, 2:286  
 Foramen magnum  
   anatomy of, 2:284  
   AP axial projection of, 2:318-319  
   trauma of, 2:318-319  
 Foramina  
   anatomy of, 1:68  
   cervical intervertebral  
     description of, 1:399  
     projections of  
       AP axial oblique, 1:426-427  
       oblique hyperflexion-extension, 1:427  
       overview, 1:392t  
       PA axial oblique, 1:428-429  
       in RAO and LAO positions, 1:428-429  
       in RPO and LPO positions, 1:426-427  
   intervertebral  
     anatomy of, 1:396, 1:399  
     cervical. *see* Foramina, cervical intervertebral  
     of fifth lumbar vertebra, 1:460-461  
     Kovács method, 1:460-461  
     of lumbar region, 1:403  
     projections of  
       overview, 1:393t  
       PA axial oblique, 1:460-461  
       positioning rotations for, 1:399t  
       in RAO and LAO positions, 1:460-461  
     of thoracic region, 1:401  
   jugular  
     anatomy of, 3:136  
     Chaussé II method, 2:426  
     Eraso modification, 2:454-455  
     Kemp Harper method, 2:454-455  
     projections of  
       AP axial, 2:426  
       overview, 2:424t  
       submentovertical axial, 2:454-455

- Foramina—*cont'd*  
 mental, 2:292  
 pelvic sacral, 1:404  
 transverse, 1:398  
 vertebral, 1:396
- Forearm  
 anatomy of, 1:93  
 dual x-ray absorptiometry of, 3:521-522  
 projections for  
 AP, 1:138-139  
 chart for, 1:98  
 lateral, 1:140  
 overview, 1:90t  
 proximal  
 in acute flexion, 1:148  
 AP projection of, 1:147  
 PA projection of, 1:148  
 radius  
 anatomy of, 1:93  
 articulations of, 1:97  
 head, lateral projection, 1:150-151  
 ulna, 1:93
- Foreign body  
 definition of, 1:538, 2:42  
 localization of  
 aspirated objects, 3:209-210  
 in esophagus, 2:135  
 in eye, 2:344  
 swallowed objects, 3:210
- Fossa, 1:74
- Foundation exposure, 1:35
- Fourth ventricle, 3:4, 3:136, 3:139
- Fovea capitis, 1:346-347
- Fowler's position, 1:80-1:81
- Fractionation, 3:575
- Fractures  
 basal, 2:296  
 Bennett's, 1:99  
 blowout, 2:296  
 Boxer's, 1:99  
 bucket, 3:182, 3:185  
 buckle, 1:99  
 child abuse, 3:182, 3:184  
 classification of, 1:74  
 clay shoveler's, 1:408  
 closed, 1:74  
 Colle's, 1:99  
 compression, 1:408  
 contre-coup, 2:296  
 definition of, 1:99, 1:168, 1:353, 1:496  
 depressed, 2:296  
 displaced, 1:74  
 fragility, 3:528  
 greenstick, 3:185  
 hangman's, 1:408  
 hip, 3:496  
 Jefferson, 1:408  
 Le Fort, 2:296  
 linear, 2:296  
 nondisplaced, 1:74  
 open, 1:74  
 osteoporotic, 3:496-497  
 Pott's, 1:242  
 Smith's, 1:99  
 tomographic evaluation of  
 healing, 3:314  
 known types, 3:313  
 occult, 3:313  
 torus, 1:99, 3:185  
 tripod, 2:296  
 vertebral, 3:496
- Fragility fractures, 3:528
- Frame, 3:383
- Frenulum, 2:39
- Frequency, 3:413, 3:458
- Friedman method, for hip, 1:374-375
- Fringe field, 3:413
- Frontal bone, 2:279
- Frontal sinus  
 anatomy of, 2:279, 2:404  
 Caldwell method, 2:412-413  
 computed tomography of, 2:404-405  
 projections of  
 chart, 2:406  
 PA axial, 2:412-413  
 technical considerations, 2:407-409  
 radiologic imaging of, 2:357  
 sectional anatomy of, 3:135
- Fuchs method  
 for dens, 1:413  
 for styloid process, 2:426
- Fulcrum  
 adjustable, 3:327  
 fixed, 3:327
- Fundus, 2:120
- Fungal disease, 1:538
- G**
- Gadolinium  
 description of, 3:400  
 magnetic resonance imaging uses of, 3:400
- Gallbladder  
 anatomy of, 2:74  
 sectional, 3:157  
 body habitus position and, 2:74, 2:95  
 cholangiography of  
 intravenous, 2:108-109  
 percutaneous hepatic, 2:110-111  
 postoperative, 2:112-113  
 diagnostic ultrasound of, 3:426-427  
 functions of, 2:74  
 opacified, 2:99-100, 2:102  
 oral cholecystography of  
 contraindications, 2:96  
 contrast media for, 2:91t, 2:91-93, 2:97  
 development of, 2:91  
 fatty meal, 2:100  
 indications, 2:96  
 intestinal tract preparation, 2:96-97  
 intravenous, 2:92  
 opacified gallbladder, 2:99-100  
 patient instructions, 2:96, 2:98  
 postprocedure instructions, 2:100  
 preliminary diet, 2:96  
 scout radiographs  
 description of, 2:98  
 inspection of, 2:99  
 projections of  
 AP, 2:95, 2:106-107  
 chart, 2:77  
 in LAO position, 2:104-105  
 lateral, 2:104-105  
 overview, 2:70t  
 PA, 2:101-103  
 PA oblique, 2:104-105  
 in prone position, 2:101  
 in right lateral decubitus position, 2:106-107  
 in right lateral position, 2:104-105  
 in upright position, 2:101-102  
 sectional anatomy of, 3:157
- Gallium, 3:467t
- Gamma camera  
 definition of, 3:462, 3:486  
 mobile, 3:469  
 modern-day, 3:469  
 multihead, 3:471
- Gamma rays, 3:486, 3:536, 3:553, 3:575
- Gantry, 3:336-337, 3:352
- Garth method, for glenoid cavity, 1:194-195
- Gas, during urinary system contrast studies, 2:208-209
- Gastritis, 2:127
- Gastrointestinal system. *see also specific anatomy*  
 aging-related changes, 3:227  
 nuclear medicine of, 3:482
- Gastrointestinal transit, 2:128
- Gastroschisis, 3:179
- Gating, 3:413
- Gauss, 3:413
- Gaynor-Hart method, for carpal canal imaging, 1:136-137
- Geiger counter, 3:469
- Genetic effects, 1:41
- Geriatrics. *see also* Aging: Elderly  
 conditions commonly found, 3:222  
 definition of, 3:220  
 demographics, 3:220-223  
 economic status, 3:221  
 radiation science practitioner's role, 3:220
- Germicides, 1:16
- Giant cell tumor, 1:242
- Glenoid cavity. *see also* Shoulder joint  
 anatomy of, 1:163  
 projections  
 AP oblique, 1:188-189  
 Apple method, 1:192-193  
 Garth method, 1:194-195  
 Grashey method, 1:188-189  
 in RPO or LPO position, 1:192-195  
 radiologic image of, 1:221
- Gliding joint, 1:72-1:73
- Glomerular capsule, 2:197
- Glomerulonephritis, 2:200
- Glomerulus, 2:197
- Glottis, 2:53
- Glucagon, 2:74, 2:240t-241t
- Gluteus maximus, 3:158-159
- Gluteus medius, 3:158-159, 3:165
- Gluteus minimus, 3:158-159, 3:165
- Goiter, 2:62
- Gomphosis, 1:71
- Gonads  
 dose received during radiographic examinations, 1:48t  
 shielding of, 1:31-32, 1:50, 1:354
- Gout, 1:99, 1:242
- Graafian follicle, 2:253
- Gracilis, 3:165
- Gradation processing, 3:370
- Gradient echo, 3:398, 3:413
- Grandy method, for cervical vertebrae, 1:422-423
- Granulomatous colitis, Welin method for imaging of, 2:173
- Granulomatous disease, 1:538
- Grashey method, for AP oblique projection of glenoid cavity, 1:188-189
- Gray, 1:43, 3:575
- Gray-level display, 3:370
- Gray-scale image, 3:352
- Greater sciatic notch, 1:345
- Greater trochanter  
 anatomy of, 1:346, 1:351  
 sectional, 3:160-161  
 radiologic imaging of, 1:356, 1:367
- Greater tubercle, of humerus, 1:94, 1:163, 1:170t
- Greenstick fracture, 3:185
- Grenz rays, 3:575
- Groove, 1:74
- Grossman principle, 3:327
- Ground state, 3:486
- Gunson method, for pharyngography, 2:57
- Gynecomastia, 2:488
- H**
- Haas method, for cranial imaging, 2:320-321
- Half-life, 3:486, 3:575
- Half-value layer, 3:575

- Hamate  
anatomy of, 1:92  
projections of  
AP, 1:123  
PA, 1:122
- Hamulus, 1:74
- Hand  
anatomy of, 1:91-92  
articulations of  
anatomy, 1:95-96  
PA oblique projection, 1:116-117  
position of, effect on shoulder AP projection,  
1:170-1:170t  
projections for  
AP, 1:120-121  
chart for, 1:98  
lateral, 1:118-120  
overview, 1:90t  
PA, 1:114-115  
PA oblique, 1:116-117
- Hand washing, 1:15
- Hangman's fracture, 1:408
- Hard copy, 3:383, 3:458
- Haustra, 2:124
- Heart  
anatomy of, 3:22-23  
sectional, 3:149  
barium use, 1:553, 1:557, 1:561  
positioning considerations, 1:540  
projections of  
AP oblique, 1:562-563  
chart, 1:539  
lateral, 1:554-557  
overview, 1:530t  
PA, 1:550-553  
PA oblique, 1:558-561  
in RAO and LAO positions, 1:558-561  
in right or left position, 1:554-557  
in RPO or LPO positions, 1:562-563  
sectional anatomy of, 3:149
- Heart rate, 3:22
- Helium-neon laser, 3:370
- Hematological system, 3:228
- Hematologic depression, 1:41
- Hematoma, 3:127
- Hemidiaphragm, 3:151
- Hemodynamics, 3:127
- Hemorrhagic shock, 2:7t
- Hemostasis, 3:127
- Henschen method, for petromastoid portion  
imaging, 2:434, 2:436
- Hepatic artery  
anatomy of, 2:72  
sectional, 3:155  
arteriograms of, 3:39
- Hepatic ducts, 2:73
- Hepatic veins, 2:72, 3:151
- Hepatic venography, 3:45
- Hepatopancreatic ampulla, 2:73
- Hernia, 2:154-155
- Herniated nucleus pulposus, 1:396, 1:408
- Heterogenous, 3:458
- Hiatal hernia  
definition of, 2:127  
Wolf method for imaging of, 2:154-155
- Hickey method  
for hip, 1:368-370  
for mastoid process imaging, 2:426
- High-resolution scans, 3:352
- Hill-Sachs defect, 1:168, 1:176, 1:191
- Hilum, 1:534, 2:196
- Hindbrain, 3:2
- Hinge joint, 1:72-1:73
- Hip  
Chassard-Lapiné method, 1:360-361  
Clements-Nakayama modification for, 1:372-373  
*Hip—cont'd*  
congenital dislocation of, 1:357, 1:365  
contrast arthrography of  
in adults, 1:590-591  
in children, 1:590  
dislocations, 1:585  
indications, 1:590  
subtraction technique, 1:590-591  
Danelius-Miller method for, 1:370-372  
description of, 1:345  
fractures of, 3:496  
Hickey method for, 1:368-370  
Hsieh method, 1:376-377  
ilium, 1:345  
ischium, 1:346  
Lauenstein method for, 1:368-370  
Lilienfeld method, 1:378-379  
mobile radiography of, 3:300  
operative radiology of, 3:282-284  
palpation of, 1:351  
projections for  
AP, 1:340-341, 1:366-367  
axial, 1:360-361  
axiolateral  
using Clements-Nakayama method, 1:372-373  
using Danelius-Miller method, 1:370-372  
using Friedman method, 1:374-375  
using Leonard-George method, 1:352  
chart, 1:353  
lateral, 1:368-370  
mediolateral oblique, 1:378-379  
overview, 1:344t  
PA, 1:376-377  
in RAO and LAO positions, 1:376-379  
pubis, 1:346  
surgical radiology of, 3:282-284  
tomography of, 3:321t, 3:326
- Hip axis length, 3:529
- Hip dysplasia, 1:353, 3:185
- Hip pinning, 3:282-284
- Hirschsprung's disease, 2:127, 3:185
- Hirtz modification, for petromastoid portion  
imaging, 2:450
- Histogram, 3:370
- Histoplasmosis, 1:538
- Hodgkin's disease, 3:572
- Holmblad method, for intercondylar fossa, 1:320-321
- Homeostasis, 3:553
- Homogenous, 3:458
- Hook of hamate, 1:92
- Horizontal plane, 1:58-1:59
- Horizontal ray method, for double-contrast  
arthrography of knee, 1:588-589
- Horseshoe kidney, 2:200
- Host computer, 3:353
- Hough method, for sphenoid strut, 2:302
- Hounsfield units, 3:335, 3:353
- Hughston method, for patella and patellofemoral  
joint, 1:331
- Humeral condyle, 1:94
- Humeroacromial joint, 1:97
- Humeroelbow joint, 1:97
- Humerus  
anatomy of, 1:94, 1:163-164  
distal  
anatomy of, 1:94  
projections for  
acute flexion, 1:148  
AP, 1:146, 1:148  
overview, 1:90t  
PA axial, 1:152  
partial flexion, 1:146  
operative radiology of, 3:290-291
- Humerus—*cont'd*  
projections for  
AP, 1:154, 1:156  
chart for, 1:98  
description of, 1:215, 1:219  
lateral, 1:155, 1:157-158  
lateromedial lateral recumbent, 1:158  
lateromedial recumbent, 1:157  
lateromedial upright, 1:155  
recumbent, 1:156  
upright, 1:154  
proximal  
anatomy of, 1:94, 1:163  
Blackett-Healy method  
for subscapular insertion, 1:199  
for teres minor insertion, 1:198  
Fisk modification, 1:196-197  
overview, 1:160t  
projections of  
AP, 1:199  
AP axial, 1:191  
PA, 1:198  
Stryker "notch" method for, 1:191  
teres minor insertion, 1:198  
surgical radiology of, 3:290-291
- Hyaline membrane disease, 1:538, 3:185
- Hydronephrosis, 2:200, 2:213, 3:127, 3:447
- Hydroxyzine hydrochloride, 2:240t-241t
- Hyoid bone, 2:52, 2:293, 3:137
- Hyperechoic, 3:458
- Hyperextension, 1:86
- Hyperflexion, 1:87
- Hyperglycemia, 2:7t
- Hypersthenic body habitus, 1:63-65, 1:64t
- Hypodermic needles, 2:243
- Hypoechoic, 3:458
- Hypoglossal canal  
Miller method, 2:456-457  
projections of  
in anterior profile, 2:456-457  
axiolateral oblique, 2:456-457  
overview, 2:424t
- Hypophyseal fossa, 3:135
- Hypophysis cerebri, 2:283, 3:2, 3:135, 3:140
- Hyposthenic body habitus, 1:63-64, 1:64t
- Hypotonic duodenography, 2:141
- Hypovolemic shock, 2:7t
- Hysterosalpingography, 2:252, 2:260-261
- I**
- Iatrogenic, definition of, 3:127
- Identification, of radiograph, 1:23
- Ileocecal valve, 2:124
- Ileum, 2:123
- Ileus, 2:76, 2:127
- Iliac crest, 1:356
- Iliacus, 3:158-159, 3:165
- Iliopsoas, 3:160-161
- Ilium  
anatomy of, 1:345  
AP and PA oblique projections, 1:388-389  
radiologic imaging of, 1:367  
sectional anatomy of, 3:158-159, 3:165
- Image coregistration, 3:553
- Image intensifier, 3:383
- Image plate reader, 3:358, 3:370
- Image processor, 3:376, 3:383
- Image reader, for computed radiography images,  
1:33
- Image receptor  
body habitus and, 1:63  
definition of, 1:3  
for patient protection, 1:50  
placement, 1:25-27
- Imaging plate, 3:370
- Immune system, 3:227



- Incus, 2:289  
 Independent jaws, 3:575  
 Indirect effect, 3:575  
 Indium, 3:467t  
 Infection, 3:483  
 Inferior, 1:75  
 Inferior mesenteric artery, 3:41  
 Inferior nasal conchae, 2:291  
 Inferior orbital sulci  
   anatomy of, 2:333  
   Bertel method, 2:340-341  
   projections of  
     overview, 2:274t  
     PA axial, 2:340-341  
 Inferior vena cava  
   anatomy of, 3:21  
   sectional, 3:146-147, 3:151-153, 3:155, 3:157  
   filter placement, 3:78-80  
   venography of, 3:44  
 Infraorbital foramen, 2:290  
 Infrapinatus  
   AP axial projection of, 1:200  
   insertion of, 1:200  
 Infrapinuous fossa, 1:162  
 Infundibulum, 2:253  
 Inguinal hernia, 2:127  
 Initial examination, 1:13  
 "Inlet" projection, of pelvic bones, 1:386-387  
 Innominate artery, 3:51  
 Input phosphor, 3:383  
 Inspiration  
   description of, 1:37  
   imaging considerations, 1:542  
   lung activity during, 1:534  
   projections of  
     AP, 2:58  
     PA, 1:552  
   quiet, 2:58  
 Inspiratory phonation tests, 2:59  
 Insulin, 2:74  
 Interchondral joint, 1:491t  
 Intercondylar eminence, 1:232, 1:309  
 Intercondylar fossa  
   anatomy of, 1:235  
   Béclère method, 1:324-325  
   Camp-Coventry method, 1:322-323  
   Holmblad method, 1:320-321  
   projections for  
     AP axial, 1:324-325  
     chart, 1:243  
     overview, 1:229t  
     PA axial, 1:320-323  
 Interiliac plane, 1:58  
 Intermembranous ossification, 1:68  
 Internal, 1:75  
 Internal acoustic meatus, 2:286  
 Internal carotid artery, 3:141  
 International Commission on Radiological Protection, 1:46  
 Interphalangeal joints, 1:95  
 Intersinus septum, 2:406  
 Interstitial pneumonitis, 1:538  
 Intertrochanteric crest, 1:346-347  
 Intertrochanteric line, 1:346-347  
 Intertubercular groove  
   anatomy of, 1:94, 1:163  
   Fisk modification for, 1:196-197  
   projections for  
     chart for, 1:168  
     tangential, 1:196-197  
 Intervention, 3:127  
 Interventional, 3:127  
 Interventional radiology  
   definition of, 3:14  
   description of, 3:68  
   future of, 3:82  
 Interventional radiology---*cont'd*  
   inferior vena cava filter placement, 3:78-80  
   pediatric use, 3:214-216  
   transcatheter embolization, 3:73-75  
   transjugular intrahepatic portosystemic shunt, 3:81  
 Interventricular septal integrity, 3:127  
 Interventricular septum, 3:146-147  
 Intervertebral disks  
   anatomy of, 1:396, 3:149, 3:156-157  
   lumbar, 1:476-477  
 Intervertebral foramina  
   anatomy of, 1:396, 1:399  
   cervical  
     description of, 1:399  
     projections of  
       AP axial oblique, 1:426-427  
       oblique hyperflexion-extension, 1:427  
       PA axial oblique, 1:428-429  
       in RAO and LAO positions, 1:428-429  
       in RPO and LPO positions, 1:426-427  
   of fifth lumbar vertebra, 1:460-461  
   Kovács method, 1:460-461  
   of lumbar region, 1:403  
   projections of  
     overview, 1:393t  
     PA axial oblique, 1:460-461  
     positioning rotations for, 1:399t  
     in RAO and LAO positions, 1:460-461  
   of thoracic region, 1:401  
 Intervertebral joints, 1:406  
 Intestine  
   large  
     anatomy of, 2:124-125  
     anterior view of, 2:124  
     body habitus and, 2:125  
     Chassard-Lapiné method, 2:189  
     colostomy studies of  
       diagnostic enema, 2:190  
       equipment, 2:190  
       intestinal tract preparation, 2:190  
       patient preparation, 2:190  
       spot radiographs, 2:190-2:191  
     contrast studies of  
       air-contrast, 2:164  
       barium suspension preparation, 2:166  
       double-contrast  
         description of, 2:164  
         single-stage procedure, 2:170-171  
         Welin procedure, 2:172-173  
       enema apparatus  
         description of, 2:165-166  
         insertion of, 2:167  
       intestinal tract preparation, 2:165  
       media for, 2:164  
       patient preparation and care, 2:166-167  
       single-contrast  
         administration of contrast medium, 2:168-169  
         description of, 2:164-165  
         positioning of opacified colon, 2:169  
       defecography of, 2:192  
     opacified  
       positioning of, 2:169  
       radiographic studies of, 2:174  
     parts of, 2:124  
     peristalsis, 2:128  
     projections of  
       AP, 2:180, 2:185-186, 2:188  
       AP axial, 2:181  
       AP oblique, 2:182-183  
       axial, 2:189  
       in decubitus positions  
         considerations for, 2:184  
         left lateral, 2:186  
         right lateral, 2:185  
         right or left ventral, 2:187  
   small  
     anatomy of, 2:122-123  
     sectional, 3:158-159  
     complete reflux examination of, 2:161  
     divisions of, 2:123  
     enteroclysis of, 2:161  
     fistula of, 2:90  
     gastrointestinal intubation examination of, 2:162-163  
     peristalsis, 2:128  
     projections of  
       AP, 2:158-160  
       overview, 2:118t  
       PA, 2:158-159  
     radiologic examination of  
       barium administration, 2:157  
       patient positioning, 2:157  
       preparations, 2:157  
     sectional anatomy of, 3:158-159  
 Intima, 3:458  
 Intracoronary stent, 3:116, 3:127  
 Intrauterine devices  
   localization of, 2:269  
   types of, 2:269  
 Intravascular ultrasound catheter, 3:119-121  
 Intravenous cholangiography, 2:108-109  
 Intravenous urography  
   contraindications, 2:213  
   description of, 2:203  
   indications, 2:213  
   procedure, 2:214-215  
   radiographs for, 2:215  
   trauma uses, 2:34  
 Intraventricular foramen, 3:4  
 Intussusception, 2:127, 3:185  
 Inversion, 1:87  
 Inversion recovery, 3:398, 3:413  
 In vitro, 3:486  
 In vivo, 3:486  
 Involution, of breasts, 2:465  
 Iodine-131  
   neck/total-body, 3:482  
   radiopharmaceutical use, 3:467t  
   thyroid uptake measurement, 3:481  
 Ionization, 3:575  
 Ionizing radiation, 3:575  
 Ipsilateral, 1:75  
 Irregular bones, 1:69  
 Ischemia, 3:127, 3:458  
 Ischial tuberosity, 1:346  
 Ischium  
   anatomy of, 1:346  
   projections of, 1:384-385  
   sectional anatomy of, 3:160-161  
 Isherwood method, for subtalar joint  
   with lateral rotation, 1:290  
   with medial rotation ankle, 1:290  
   with medial rotation foot, 1:289  
 Islet cells, 2:74  
 Isocentric, 3:575  
 Isocentric machine, 3:562  
 Isodose curve, 3:575

Isodose line/curve, 3:569  
 Isoechoic, 3:458  
 Isointensity profiles, 1:53  
 Isotopes, 3:463, 3:486, 3:575  
 Isotropic, 3:553

## J

Jefferson fracture, 1:408  
 Jejunum, 2:123  
 Joint(s)  
   cartilaginous  
     description of, 1:71  
     symphysis, 1:71  
     synchondrosis, 1:71  
   classification of  
     functional, 1:71  
     structural, 1:70t, 1:71  
   fibrous, 1:71  
   localization of, for orthoroentgenography, 1:578-581  
   lower limb, 1:238t  
   upper limb, 1:95t, 1:95-97  
 Joint capsule tear, 1:585  
 Joint Commission on Accreditation of Healthcare Organizations, 3:231  
 Joint effusion, 1:99  
 Judd method, for imaging dens of atlas, 1:416  
 Judet method, for acetabulum, 1:382-383  
 Jugular foramina  
   anatomy of, 2:285, 3:136  
   Chaussé II method, 2:426  
   Eraso modification, 2:454-455  
   Kemp Harper method, 2:454-455  
   projections of  
     AP axial, 2:426  
     overview, 2:424t  
     submentovertical axial, 2:454-455  
 Jugular notch, 1:489

## K

Kandel method, for congenital clubfoot, 1:278  
 Kasabach method, for dens, 1:417  
 Kemp Harper method, for jugular foramina, 2:454-455  
 Kidneys  
   age-related changes, 3:228  
   anatomy of, 2:196-197  
   diagnostic ultrasound of, 3:428-432  
   dynamic scan of, 3:482  
   function of, 2:195  
   parenchyma. *see* Renal parenchyma  
   sectional anatomy of, 3:155, 3:157  
   tomography of, 3:315

Kilovoltage  
   for computed radiography, 1:34  
   description of, 1:37-38

Kinetics, 3:553

Kite method, for congenital clubfoot, 1:275

## Knee

anatomy of, 1:236-237, 1:240  
 contrast arthrography of  
   double-contrast, 1:588-589  
   horizontal ray method, 1:588-589  
   vertical ray method, 1:586-587  
 ligaments of, 1:236-237  
 mobile radiography of, 3:300  
 projections for  
   AP, 1:308-309, 1:314, 1:340-341  
   AP oblique, 1:316-317  
   chart, 1:243  
   in flexion position, 1:315  
   lateral, 1:312-313  
   in lateral rotation, 1:316, 1:318  
   in medial rotation, 1:317, 1:319  
   in mediolateral position, 1:312-313  
   overview, 1:229t

## Knee—*cont'd*

projections for—*cont'd*  
   PA, 1:310-311, 1:315  
   PA oblique, 1:318-319  
   Rosenberg method, 1:315  
   in standing position, 1:315  
   weight-bearing method  
     in flexion position, 1:315  
     in standing position, 1:314  
 Kovács method, for intervertebral foramina, 1:460-461  
 Kurzbauer method, for sternoclavicular articulations, 1:512-513  
 Kyphosis, 1:395, 1:408, 3:529  
 Kyphotic curves, of vertebral column, 1:395

## L

Lacrimal bones, 2:290  
 Lacrimal canaliculi, 2:348  
 Lacrimal foramen, 2:290  
 Lacrimal gland, 2:348  
 Lacrimal papilla, 2:348  
 Lactiferous ductules, 2:466  
 Landmarking, 3:383  
 Laquerrière-Pierquin method, for scapular spine tangential projection, 1:222-223

## Large intestine

anatomy of, 2:124-125  
 anterior view of, 2:124  
 body habitus and, 2:125  
 Chassard-Lapiné method, 2:189  
 colostomy studies of  
   diagnostic enema, 2:190  
   equipment, 2:190  
   intestinal tract preparation, 2:190  
   patient preparation, 2:190  
   spot radiographs, 2:190-2:191  
 contrast studies of  
   air-contrast, 2:164  
   barium suspension preparation, 2:166  
   double-contrast  
     description of, 2:164  
     single-stage procedure, 2:170-171  
     Welin procedure, 2:172-173  
   enema apparatus  
     description of, 2:165-166  
     insertion of, 2:167  
   intestinal tract preparation, 2:165  
   media for, 2:164  
   patient preparation and care, 2:166-167  
   single-contrast  
     administration of contrast medium, 2:168-169  
     description of, 2:164-165  
     positioning of opacified colon, 2:169  
 defecography of, 2:192  
 opacified  
   positioning of, 2:169  
   radiographic studies of, 2:174  
 parts of, 2:124  
 peristalsis, 2:128  
 projections of  
   AP, 2:126, 2:180, 2:185-186, 2:188  
   AP axial, 2:126, 2:181  
   AP oblique, 2:126, 2:182-183  
   axial, 2:189  
   chart, 2:126  
   in decubitus positions  
     considerations for, 2:184  
     left lateral, 2:186  
     right lateral, 2:185  
     right or left ventral, 2:187  
   in LAO position, 2:178  
   lateral, 2:126, 2:179, 2:187  
   in LPO position, 2:182  
   overview, 2:118t

## Large intestine—*cont'd*

projections of—*cont'd*  
   PA, 2:126, 2:174-175, 2:185-186  
   PA axial, 2:126, 2:176  
   PA oblique, 2:126, 2:177-178  
   in RAO position, 2:177  
   in right or left position, 2:179  
   in RPO position, 2:183  
   in upright position, 2:188  
 Laryngopharyngography  
   description of, 2:57-59  
   phonation  
     inspiratory, 2:59  
     normal (expiratory), 2:58  
   positive-contrast, 2:60-61  
   quiet inspiration, 2:58  
   Valsalva's maneuver, 2:59  
   modified, 2:59  
 Larynx  
   anatomy of, 2:52-53, 3:137  
   cancer of, 3:573  
   functions of, 2:52  
   projections of  
     AP, 2:64-65  
     lateral, 2:66-67  
     overview, 2:50t  
     in right or left position, 2:66-67  
   tomolaryngography of, 2:59  
 Laser printer, 3:383  
 Latent image, 3:370  
 Lateral, 1:75  
 Lateral condyle, 1:232  
 Lateral epicondyle  
   anatomy of, 1:94, 1:234  
   AP projection of, 1:139  
   radiologic imaging of, 1:309  
 Lateral intercondylar tubercle, 1:232  
 Lateral malleolus, 1:233  
 Lateral meniscus, 1:237, 1:589  
 Lateral position, 1:81  
 Lateral projection. *see also specific anatomy, projections for*  
   definition of, 1:78  
   illustration of, 1:78  
 Lateral radiographs, 1:10-11  
 Lateral ventricle, 3:2, 3:139-141  
 Latissimus dorsi, 3:146-147  
 Lauenstein method, for hip, 1:368-370  
 Law method, for petromastoid portion imaging  
   modified, 2:432-433  
   original, 2:430-431  
 Lawrence method, for shoulder imaging, 1:174-175  
 Lead  
   thickness of, 1:52t  
   x-ray attenuation values for, 1:52t  
 Le Fort fracture, 2:296  
 Left anterior oblique position, 1:82  
 Left posterior oblique position, 1:83  
 Left ventricle  
   angiography of, 3:108  
   sectional anatomy of, 3:146-147  
 Leg. *see also* Fibula; Tibia  
   anatomy of, 1:232-233  
   projections for  
     AP, 1:302-303  
     AP oblique, 1:306-307  
     chart, 1:243  
     lateral, 1:304-305  
     in lateral rotation, 1:306-307  
     in medial rotation, 1:306-307  
     in mediolateral position, 1:304-305  
     overview, 1:229t  
 Legg-Calve-Perthes disease, 1:353, 3:185  
 Lentiform nucleus, 3:134  
 Leonard-George method, for hip, 1:352  
 Lesion, 3:127, 3:575

- Lesser sciatic notch, 1:346
  - Lesser trochanter, 1:346, 1:356
  - Lesser tubercle, of humerus, 1:94, 1:163
  - Leukemia, secondary to radiation exposure, 1:42
  - Lewis and Holly method, for tangential projection of sesamoid bones, 1:252-253
  - Ligaments
    - anterior cruciate
      - anatomy of, 1:236
      - double-contrast arthrography of, 1:589
    - Cooper's, 2:465
    - falciform, 2:72
    - fibular collateral, 1:236
    - posterior cruciate
      - anatomy of, 1:236
      - double-contrast arthrography of, 1:589
    - tibial collateral, 1:236
    - transverse atlantal, 1:397
  - Ligament tear, 1:585
  - Ligamentum teres, 3:152-153
  - Light pipe, 3:486
  - Lilienfeld method
    - for hip PA oblique projection, 1:378-379
    - for pelvic bones superoinferior axial projection, 1:386
    - for scapula PA oblique projection, 1:216-217
  - Limb
    - entrance skin exposure for, 1:48t
    - length measurement of
      - computed tomography, 1:582
      - orthoroentgenography
        - joint localization, 1:578-581
        - part positioning, 1:578
        - patient positioning, 1:578
        - radiation protection, 1:578
    - lower
      - anatomy of, 1:241t
      - AP projection of, 1:340-341
      - articulations of, 1:238-240
      - length measurement of
        - computed tomography, 1:582
        - orthoroentgenography
          - joint localization, 1:578-581
          - part positioning, 1:578
          - patient positioning, 1:578
          - radiation protection, 1:578
      - radiation protection, 1:244
      - venography of, 3:49
      - weight-bearing method for, 1:340-341
    - tomography of, 3:321t
    - upper
      - anatomy of, 1:98
      - joints of, 1:95t, 1:95-97
      - trauma radiographs, 2:27-29
  - Lindblom method, for pulmonary apices, 1:566-567
  - Line, 1:74
  - Linear accelerators, 3:563-565, 3:575
  - Linear energy transfer, 3:560, 3:575
  - Linear fracture, 2:296
  - Linear tomographic motion, 3:327
  - Lingula, 1:534
  - Liver
    - anatomy of, 2:72
    - contrast media for, 2:93
    - diagnostic ultrasound of, 3:422-423
    - digestive functions of, 2:71
    - hilum of, 2:72
    - nuclear medicine scans, 3:482
    - physiologic functions of, 2:72
    - sectional anatomy of, 3:146-147, 3:151, 3:155
  - Local cerebral blood flow, 3:553
  - Local metabolic rate of glucose utilization, 3:553
  - Long bones
    - description of, 1:68
  - Long bones---cont'd
    - length measurement of
      - computed tomography, 1:582
      - orthoroentgenography
        - joint localization, 1:578-581
        - part positioning, 1:578
        - patient positioning, 1:578
        - radiation protection, 1:578
  - Longitudinal arch, of foot, 1:270-271
  - Longitudinal quality control, 3:529
  - Longitudinal sulcus, 3:2
  - Lordosis, 1:408
  - Lordotic curves, of vertebral column, 1:395
  - Lordotic position
    - for clavicle projections, 1:207
    - description of, 1:84
    - for pulmonary apices projections, 1:536, 1:566-567
  - Lorenz method, for scapula PA oblique projection, 1:216-217
  - Lower limb. *see also specific anatomy*
    - anatomy of, 1:241
    - AP projection of, 1:340-341
    - articulations of, 1:238-240
    - length measurement of
      - computed tomography, 1:582
      - orthoroentgenography
        - joint localization, 1:578-581
        - part positioning, 1:578
        - patient positioning, 1:578
        - radiation protection, 1:578
    - pathology of, 1:242
    - radiation protection, 1:244
    - trauma radiographs, 2:30-32
    - venography of, 3:49
    - weight-bearing method for, 1:340-341
  - Lumbar vertebrae
    - anatomy of, 1:394, 1:402-403
    - sectional, 3:164
    - dual x-ray absorptiometry of, 3:516-518, 3:522
    - intervertebral foramina of, 1:403
    - landmarks of, 1:62t
    - magnetic resonance imaging of, 3:404
    - mobile radiography of, 3:298-299
    - operative radiology of, 3:280-281, 3:298-299
    - projections of
      - AP, 1:448-451
      - chart, 1:409
      - lateral, 1:452-453
      - oblique, 1:486
      - overview, 1:393t
      - PA, 1:448-451
      - in right or left position, 1:452-453
    - sectional anatomy of, 3:164
    - surgical radiology of, 3:280-281
    - tomography of, 3:321t
    - zygapophyseal joints of, 1:403
  - Lumbosacral angle, 1:395
  - Lumbosacral junction, projections of
    - chart, 1:409
    - description of, 1:393t, 1:462-463
    - lateral, 1:454-455
    - in right or left position, 1:454-455
  - Lumbosacral vertebrae, projections of
    - AP, 1:448-451
    - lateral, 1:452-453
    - overview, 1:393t
    - PA, 1:448-451
    - in right or left position, 1:452-453
  - Lunate
    - anatomy of, 1:91, 1:96
    - projections of
      - AP, 1:123
      - PA, 1:122
  - Lung(s)
    - anatomy of, 1:533-534
    - lobular divisions, 1:534
    - positioning considerations, 1:540
    - projections of
      - AP, 1:572-573
      - AP oblique, 1:562-563
      - chart, 1:539
      - lateral, 1:554-557, 1:574
      - overview, 1:530t
      - PA, 1:550-553
      - PA oblique, 1:558-561
      - in RAO and LAO positions, 1:558-561
      - in right or left lateral decubitus positions, 1:572-573
      - in right or left position, 1:554-557
      - in RPO or LPO positions, 1:562-563
      - in ventral or dorsal decubitus positions, 1:574
    - pulmonary arteriography of, 3:36-37
    - respiratory movements, 1:534
    - sectional anatomy of, 3:149, 3:151
    - views of, 1:533
  - Lung cancer, 3:571
  - Lymph, 3:20, 3:22, 3:127
  - Lymphadenography, 3:127
  - Lymphangiography, 3:127
  - Lymphatic system, 3:20, 3:24-25
  - Lymph nodes, 3:24
  - Lymphocytes, 3:24
  - Lymphography
    - anatomy shown using, 3:84t
    - definition of, 3:127
    - definitions, 3:83
    - indications, 3:83
    - procedures
      - imaging, 3:84
      - injections, 3:84-85
  - Lymph vessels, 3:24
  - Lysholm method, for petromastoid portion imaging, 2:434-435, 2:437
- ## M
- Magnetic resonance angiography, 3:16
  - Magnetic resonance imaging
    - claustrophobia and, 3:393
    - clinical applications of
      - abdomen, 3:406
      - augmented breast, 2:481
      - central nervous system, 3:12-13, 3:402-405
      - chest, 3:405
      - cranium, 2:277
      - meniscus, 1:237
      - musculoskeletal system, 3:407-408
      - pelvis, 3:407
      - shoulder joint, 1:165
      - spinal cord, 3:12, 3:405
      - vessels, 3:408-410
    - coils for, 3:399
    - computed tomography and, comparison between, 3:351
    - contraindications, 3:13
    - contrast media, 3:400-401
    - conventional radiography and, comparison between, 3:386
    - definition of, 3:553
    - description of, 1:584
    - diffusion, 3:411
    - equipment for
      - computer room, 3:389
      - console, 3:389
      - magnet room, 3:390-391
    - examination protocols
      - imaging parameters, 3:395-398
      - imaging sequence, 3:397
      - imaging time, 3:396
      - planes, 3:395



- Magnetic resonance imaging—*cont'd*  
 examination protocols—*cont'd*  
   positioning, 3:398  
   spin echo sequences, 3:398  
 gating, 3:401-402  
 hazards associated with, 3:392  
 historical development of, 3:386  
 indications, 3:13  
 patient monitoring, 3:399  
 pediatric use, 3:212  
 perfusion, 3:411  
 positron emission tomography and, comparison  
   between, 3:532-534, 3:533t  
 principles of, 3:386  
 safety of, 3:392  
 signal production, 3:387-388  
 signal significance, 3:388  
 spectroscopy, 3:412  
 stereotactic surgery and, 3:17  
 three-dimensional imaging, 3:395
- Magnets  
 permanent, 3:390  
 resistive, 3:390  
 superconductive, 3:390
- Magnification radiography, 1:26
- Malabsorption syndrome, 2:127
- Male breast  
 calcifications of, 2:489  
 mammography of  
   description of, 2:488  
   projections, 2:488
- Male reproductive system  
 ductus deferens, 2:256  
 ejaculatory ducts, 2:256  
 overview, 2:256  
 prostate, 2:257  
 radiography of, 2:270-271  
 seminal vesicles, 2:256  
 testes, 2:256
- Malignancy, 3:575
- Malleolus, 1:74
- Malleus, 2:289
- Mammillary process, 1:402
- Mammography  
 advances in, 2:462  
 augmented breast  
   breast cancer detection rate decreases, 2:480  
   craniocaudal projection  
     with full implant, 2:482-483  
     with implant displaced, 2:484-485  
   Eklund technique, 2:481  
   mediolateral oblique projection  
     with full implant, 2:486  
     with implant displaced, 2:487  
 automatic exposure control systems, 2:470,  
   2:473  
 breast cancer detection using, 2:461  
 diagnostic, 2:464  
 digital  
   computer-aided detection and diagnosis,  
     2:528-529  
   image acquisition, 2:529  
   image display, 2:529  
 entrance skin exposure during, 1:48t  
 equipment, 2:470  
 examination technique  
   patient preparation, 2:471  
   procedures, 2:472-473  
   projections typically used, 2:471-472  
 findings of significance, 2:490-494  
 frequency of, 2:464  
 glandular dose during, 1:48t  
 goal of, 2:461  
 history of, 2:462  
 image enhancement methods  
   magnification technique, 2:496-497  
   spot compression, 2:495
- Mammography—*cont'd*  
 labeling codes, 2:472t, 2:473  
 male breast  
   description of, 2:488  
   projections, 2:488  
 mean glandular dose, 2:463  
 milk ducts, 2:528  
 milliamperage settings for, 2:470  
 nonpalpable lesions  
   localization of  
     description, 2:518  
     fine-needle aspiration biopsy, 2:518  
     needle-wire, 2:518  
     with specialized compression plate, 2:519-  
       521  
     stereotactic procedures, 2:524-527  
     without specialized compression plate,  
       2:521-523  
   radiography of biopsy specimen, 2:527  
   spot compression technique, 2:495  
 palpable lesions  
   spot compression technique, 2:495  
   tangential projection, 2:508  
 projections  
   caudocranial, 2:475, 2:490t, 2:510-511  
   chart, 2:469  
   craniocaudal, 2:474, 2:476-477, 2:482-485,  
     2:491-492  
   craniocaudal for cleavage, 2:475, 2:504-505  
   craniocaudal with roll lateral, 2:475, 2:490t,  
     2:506-507  
   craniocaudal with roll medial, 2:475, 2:490t,  
     2:506-507  
   exaggerated craniocaudal, 2:475, 2:490t,  
     2:502-503  
   lateromedial, 2:474, 2:490t  
   lateromedial oblique, 2:475, 2:514-515  
   mediolateral, 2:474, 2:490t, 2:498-499  
   mediolateral oblique, 2:474, 2:478-479,  
     2:486-487, 2:491  
   mediolateral oblique for auxiliary tail, 2:475,  
     2:490t  
   mediolateral oblique for axillary tail,  
     2:512-513  
   90-degree lateromedial, 2:500-501  
   90-degree mediolateral, 2:498-499  
   superolateral to inferomedial, 2:475, 2:490t,  
     2:516-517  
   supplemental, 2:490t  
   tangential, 2:475, 2:490t, 2:508-509  
   risk versus benefit, 2:463  
   screening, 2:464  
   systems evolution, 2:470
- Mammography Quality Standards Act, 2:463
- Mandible  
 anatomy of, 2:292  
 body, projections of  
   overview, 2:352t  
   PA, 2:384  
   PA axial, 2:385  
 panoramic tomography of, 2:398-399  
 projections of  
   axiolateral oblique, 2:386-388  
   chart, 2:353  
   overview, 2:352t  
   PA, 2:384  
   PA axial, 2:385  
   submentovertical, 2:389  
   verticosubmental, 2:390-391
- Mandibular condyle, 2:441
- Mandibular fossa, 2:286
- Mandibular notch, 2:292
- Mandibular rami  
 projections of  
   axiolateral oblique, 2:388  
   chart, 2:353  
   overview, 2:352t
- Mandibular rami—*cont'd*  
 projections of—*cont'd*  
   PA, 2:382  
   PA axial, 2:383  
   sectional anatomy of, 3:140
- Mandibular symphysis, projections of  
 AP axial, 2:380-381  
 overview, 2:352t  
 in supine position, 2:380-381
- Manubriosternal joint  
 anatomy of, 1:491t  
 description of, 1:492
- Manubrium, 1:489, 3:149
- Markers, 1:24-25
- Mask, 3:383
- Masseter muscle, 3:140
- Mastication, 2:39
- Mastoid air cells, 2:286
- Mastoiditis, 2:296
- Mastoid process  
 Hickey method, 2:426  
 projections of  
   AP tangential, 2:426  
   general procedures, 2:427-429  
   overview, 2:424t  
   PA tangential, 2:426
- Matrix, 3:353, 3:370, 3:383
- Maxilla, 3:139
- Maxillary sinus  
 anatomy of, 2:403  
 description of, 2:290, 2:357  
 development of, 2:403  
 projections of  
   chart, 2:406  
   PA, 2:422  
   parietoacanthial, 2:414-417  
   technical considerations, 2:407-409
- Maximum intensity projection, 3:353
- Mayer method, for petromastoid portion imaging,  
 2:442-445
- May method, for zygomatic arches, 2:376-377
- Mean, 3:529
- Mean marrow dose, 1:48
- Meatus, 1:74
- Meckel's diverticulum, 2:127
- Medial, 1:75
- Medial condyle, 1:232
- Medial epicondyle  
 anatomy of, 1:94, 1:234  
 projection of  
   AP, 1:139  
   AP oblique, 1:144  
   radiologic imaging of, 1:309
- Medial intercondylar tubercle, 1:232
- Medial meniscus, 1:237, 1:588-589
- Median nerve, 1:92
- Mediastinum  
 anatomy of, 1:535-536  
 description of, 1:531  
 superior, projections of  
   lateral, 1:546-547  
   in right or left position, 1:546-547
- Medical dosimetrist, 3:556, 3:575
- Medical physicist, 3:575
- Medical terminology, 1:88-1:88t
- Medulla oblongata, 3:135, 3:141
- Medullary cavity, 1:66
- Medulloblastoma, 3:573
- Memory, 3:383
- Meninges  
 anatomy of, 3:3  
 definition of, 3:127
- Meniscus  
 anatomy of, 1:72  
 lateral, 1:589  
 medial, 1:588-589  
 tear of, 1:585

- Menstrual cycle, 2:254  
 Mental foramina, 2:292  
 Mental protuberance, 2:292  
 Meperidine hydrochloride, 2:240t-241t  
 Merchant method, for patella and patellofemoral joint, 1:332-333  
 Mesentery, 2:71  
 Metacarpals  
   anatomy of, 1:91  
   articulation of, 1:96  
   PA oblique projection of, 1:116-117  
 Metacarpophalangeal joints, 1:96  
   first, 1:112-113  
 Metastable, 3:486  
 Metastases, 1:99, 1:168, 1:242, 1:353, 1:496, 1:538, 2:76, 2:296, 3:575  
 Metatarsals  
   anatomy of, 1:231  
   radiologic imaging of, 1:261, 1:274  
 Metatarsophalangeal articulations, 1:240  
 Method, 1:85  
 Metric conversion system, 1:28  
 Microbial fallout, 3:303  
 Micturition, 2:198  
 Midaxillary plane, 1:58  
 Midazolam hydrochloride, 2:240t-241t  
 Midbrain, 3:2  
 Middle cerebellar peduncle, 3:141  
 Middle ear, 3:320t, 3:324  
 Middle nasal conchae, 2:280  
 Midsagittal plane, 1:58  
 Milk ducts of breast, 2:528  
 Miller-Abbott tube, for gastrointestinal intubation procedures, 2:162-163  
 Milliamperage, 1:37  
 Milliroentgen, 1:43  
 Minor surgery, 1:17  
 Misregistration, 3:377, 3:383  
 Mitral regurgitation, 3:108-109  
 M-mode, 3:458  
 Mobile radiography  
   anode heel effect, 3:236-237  
   cathode placement, 3:236t  
   grid of, 3:235-236  
   isolation considerations, 3:239  
   mobile x-ray machines  
     battery-operated, 3:235  
     capacitor-discharge, 3:235  
     description of, 3:234  
   operating room uses of  
     cervical spine, 3:296-297  
     extremities, 3:300-302  
     hip, 3:300  
     knee, 3:300  
     lumbar spine, 3:298-299  
     shoulder joint, 3:301  
     thoracic spine, 3:298-299  
     tibia, 3:301  
   patient considerations  
     asepsis, 3:241  
     assessment of condition, 3:240  
     fractures, 3:241  
     interfering devices, 3:241  
     mobility, 3:241  
     positioning, 3:241  
   principles of, 3:234  
   procedure, 3:240  
   projections  
     abdomen  
       AP, 3:246-249  
       in left lateral decubitus position, 3:248-249  
       PA, 3:248-249  
     cervical spine, 3:256-257, 3:296-297  
     chest  
       AP, 3:242-245  
       PA, 3:244-245  
       in right or left lateral decubitus position, 3:244-245  
       in upright or supine position, 3:242-243  
     femur  
       AP, 3:252-253  
       lateral, 3:254-255  
       in mediolateral or lateromedial dorsal decubitus position, 3:254-255  
     lumbar spine, 3:298-299  
     pelvis, 3:250-251  
     thoracic spine, 3:298-299  
   radiation safety, 3:238  
   radiographic technique charts, 3:237  
   source-to-image receptor distance, 3:237  
   trauma uses of, 2:3  
 Modified Titterton method, for zygomatic arch imaging, 2:354  
 Moiré, 3:370  
 Monitoring devices, for personnel exposure  
   anatomic placement of, 1:54  
   film badge, 1:54  
   pocket ionization chambers, 1:54  
   thermoluminescent dosimetry badges, 1:54  
 Moore method, for sternum, 1:502-503  
 Morphine sulfate, 2:240t-241t  
 Morphometric x-ray absorptiometry, 3:529  
 Mortise joint projections  
   AP oblique, 1:296-297  
   overview, 1:229t  
 Motion  
   involuntary, 1:18-19  
   types of, 1:18  
   voluntary, 1:19  
 Mouth, 2:39  
 Multifformat camera, 3:383  
 Multileaf collimation and collimator, 3:565, 3:575  
 Multiplanar reconstruction unit, 3:340  
 Multiple myeloma, 1:353, 1:408, 1:496, 2:296  
 Muscle  
   involuntary, 1:18-19  
   voluntary, 1:19  
 Musculoskeletal system, 3:226  
 Myelography  
   computed tomography, 3:11  
   contrast media for, 3:6-7  
   definition of, 3:6  
   examining room for, 3:7  
   patient positioning, 3:8  
   pediatric use, 3:212  
   procedure, 3:8-9  
 Myelomeningocele, 3:178  
 Myocardial infarction, 3:127  
 Myocardium, 3:22, 3:127  
 Myometrium, 3:458  
 N  
 Nail  
   femur, 3:285-286  
   tibia, 3:288-289  
 Naloxone hydrochloride, 2:240t-241t  
 Narcan. *see* Naloxone hydrochloride  
 Nasal bones  
   description of, 2:290  
   projections of  
     chart, 2:353  
     lateral, 2:368-369  
     overview, 2:352t  
     in right or left positions, 2:368-369  
     tangential, 2:370-371  
 Nasal conchae  
   inferior, 2:291  
   middle, 2:280  
   superior, 2:280  
 Nasal spine, 2:279  
 Nasolacrimal drainage system  
   dacryocystography of, 2:348-349  
   description of, 2:348  
 Nasolacrimal duct, 2:348  
 Nasopharyngography  
   indications, 2:54  
   opaque-contrast, 2:56  
   positive-contrast, 2:54-56  
   submentovertebral, 2:54-55  
 Nasopharynx, 2:52, 3:139-3:140  
 National Council for Radiation Protection and Measurements, 1:45-1:46t  
 Navicular  
   anatomy of, 1:231  
   radiologic imaging of, 1:274  
 Neck  
   anatomy of, 2:51  
   divisions of, 2:51  
   sectional anatomy of, 3:148-149  
 Needle stick injuries, 1:15  
 Neer method, for shoulder joint, 1:186t  
 Neonate  
   mobile radiography projections of  
     abdomen  
       AP, 3:258-261  
       lateral, 3:262-263  
       in right or left dorsal decubitus position, 3:262-263  
     chest  
       AP, 3:258-261  
       lateral, 3:262-263  
       in right or left dorsal decubitus position, 3:262-263  
     neurosonography, 3:436-437  
 Nephrectomy, 3:128  
 Nephrolithotomy, percutaneous, 3:77  
 Nephron, 2:197  
 Nephrostomy  
   definition of, 3:128  
   indications, 3:75  
   tube placement, 3:75-76  
 Nephrotomography, 3:321t  
   bolus injection, 2:202, 2:221  
   contraindications, 2:221  
   contrast media for, 2:221  
   indications, 2:221  
   infusion, 2:202, 2:221  
   patient preparation, 2:221  
   procedure, 2:222-223  
 Nephrotoxic, 3:128  
 Nephrourography, 2:221  
 Neurosonography, neonatal, 3:436-437  
 Neutron, 3:463, 3:486  
 Nipple, 2:465  
 Noctec. *see* Chloral hydrate  
 Noise, 3:370, 3:413  
 Nölke method, for sacral vertebral canal, 1:474-475  
 Noninvasive technique, 3:458  
 Nonionic contrast medium, 3:383  
 Nonocclusive, 3:128  
 Norgaard method, for AP projection of hand, 1:120-121  
 Notch, 1:74  
 Nuclear cardiology  
   central nervous system, 3:480  
   description of, 3:479  
   endocrine system, 3:481-482  
   exercise radionuclide angiography, 3:479  
   thallium-201 myocardial perfusion study, 3:479

- Nuclear medicine  
 bone scintigraphy, 3:478  
 gastrointestinal system, 3:482  
 genitourinary, 3:482  
 history of, 3:462  
 imaging methods  
   dynamic, 3:473  
   positron emission tomography, 3:476  
   quantitative analysis, 3:472  
   single photon emission computed tomography, 3:474-475  
   static, 3:472  
   whole-body, 3:473  
 infection imaging, 3:483  
 instrumentation  
   collimator, 3:470  
   computers, 3:471-472  
   crystal pipe, 3:470  
   detector electronics, 3:470  
   gamma camera  
     mobile, 3:469  
     modern-day, 3:469  
     multihead, 3:471  
   light pipe, 3:470  
   radioactive detectors  
     gas-filled, 3:469  
     scintillation, 3:469  
 nuclear physics, 3:463-464  
 patient preparation for, 3:476  
 pediatric use, 3:216  
 principles of, 3:462-466  
 radiation safety, 3:468  
 respiratory imaging, 3:483  
 therapeutic, 3:483  
 tumor studies, 3:483  
 in vitro and in vivo hematologic studies, 3:483  
 Nuclear particle accelerator, 3:553  
 Nuclear reactor, 3:486  
 Nucleus, 3:413  
 Nucleus pulposus, 1:396  
 Nuclide, 3:463, 3:486  
 Nutrient artery, 1:68  
 Nutrient foramen, 1:68
- O**
- Object-to-image receptor distance, 1:6, 3:29  
 Oblique plane, 1:59, 3:458  
 Oblique position  
   description of, 1:82  
   left anterior, 1:82  
   oblique projection and, relationship between, 1:83  
   right anterior, 1:82  
 Oblique projection  
   description of, 1:78  
   illustration of, 1:79  
   oblique position and, relationship between, 1:83  
   posteroanterior, 1:78-79  
 Obturator externus, 3:160-161  
 Obturator internus, 3:160-161  
 Occipital bone, 2:284-285  
 Occipital condyles, 2:285  
 Occipitoatlantal joints, 2:285  
 Occlusal plane, 1:58  
 Occlusion, 3:128  
 Occupational radiation exposure  
   description of, 1:49  
   guidelines to minimize, 1:53  
 Olecranon fossa, 1:94  
 Olecranon process  
   anatomy of, 1:93  
   projections for  
   AP oblique, 1:144  
   lateral, 1:140  
   overview, 1:90t  
   PA axial, 1:153
- Omenta, 2:71  
 Omphalocele, 3:179  
 Oncologist, 3:576  
 Oncology nurse, 3:556  
 Operating room  
   aseptic techniques, 3:273b  
   cannulated hip screws, 3:282-284  
   cervical spine imaging, 3:279  
   chest imaging, 3:278  
   contamination, 1:16-17  
   description of, 3:266  
   equipment  
   cleaning of, 3:275  
   description of, 3:274  
   femoral arteriogram, 3:294-295  
   femur nail, 3:285-287  
   hip imaging, 3:282-284  
   hip pinning, 3:282-284  
   humerus imaging, 3:290-291  
   lumbar spine imaging, 3:280-281  
   mobile radiography procedures  
   cervical spine, 3:296-297  
   extremities, 3:300-302  
   hip, 3:300  
   knee, 3:300  
   lumbar spine, 3:298-299  
   shoulder joint, 3:301  
   thoracic spine, 3:298-299  
   tibia, 3:301  
   operative cholangiography, 3:276-277  
   pituitary tumor, transsphenoidal resection of, 3:292-293  
   scope of, 3:266b  
   sterility  
   aseptic techniques, 3:273b  
   interventional radiology considerations, 3:271-272  
   maintenance of, 3:270  
   surgical team  
   attire for, 3:268-269  
   members of, 3:266-267  
   personal hygiene of, 3:269  
   tibial arteriogram, 3:294-295  
   tibia nail, 3:288-289  
   transsphenoidal resection of pituitary tumor, 3:292-293  
 Operative cholangiography, 3:276-277  
 Operative radiology. *see* Surgical radiology  
 Optical density  
   definition of, 1:4  
   illustration of, 1:5  
 Optic canal  
   anatomy of, 2:283  
   projections of  
   chart, 2:297  
   orbitoparietal oblique, 2:336-337  
   overview, 2:274t  
   parieto-orbital oblique, 2:334-335  
   Rhese method, 2:334-337  
 Optic chiasm, 3:136, 3:139-140  
 Optic foramen  
   anatomy of, 2:283, 2:332  
   projections of, 2:274t, 2:297  
 Optic groove, 2:283  
 Oral cavity cancer, 3:572  
 Oral cholecystography  
   contraindications, 2:96  
   contrast media for, 2:91t, 2:91-93, 2:97  
   development of, 2:91  
   fatty meal, 2:100  
   indications, 2:96  
   intestinal tract preparation, 2:96-97  
   intravenous, 2:92  
   opacified gallbladder, 2:99-100  
   patient instructions, 2:96, 2:98  
   postprocedure instructions, 2:100
- Oral cholecystography—*cont'd*  
 preliminary diet, 2:96  
 scout radiographs  
   description of, 2:98  
   inspection of, 2:99  
 Oral vestibule, 2:39  
 Orbit  
   anatomy of, 2:332  
   fractures of, 2:333  
   function of, 2:333  
 Orbitoparietal oblique projection, of optic canal and foramen, 2:336-337  
 Organ dose, 1:48  
 Oropharynx, 2:39, 2:52, 3:140  
 Orthoroentgenography  
   joint localization, 1:578-581  
   part positioning, 1:578  
   patient positioning, 1:578  
   radiation protection, 1:578  
 Osgood-Schlatter disease, 1:242, 3:185  
 Ossification, of bone  
   endochondral, 1:68  
   intermembranous, 1:68  
 Osteoarthritis, 1:99, 1:168, 1:242, 1:353, 1:408, 3:226  
 Osteoblasts, 3:529  
 Osteochondroma, 1:242, 3:185  
 Osteoclasts, 3:492-493, 3:529  
 Osteogenesis imperfecta, 3:179  
 Osteoid osteoma, 1:242  
 Osteology, 1:58  
 Osteoma, 2:296  
 Osteomalacia, 1:242, 3:185, 3:529  
 Osteomyelitis, 1:1, 1:99, 1:242, 2:296  
 Osteopenia, 3:494, 3:529  
 Osteopetrosis, 1:99, 1:168, 1:242, 1:353, 1:408, 1:496, 2:296  
 Osteophytosis, 3:516, 3:529  
 Osteoporosis  
   cause of, 3:494  
   definition of, 1:99, 1:168, 1:353, 1:408, 1:496, 2:296, 3:494, 3:529  
   description of, 3:484  
   fractures, 3:496  
   incidence of, 3:494  
   primary, 3:495  
   resources for, 3:530  
   risk factors, 3:494  
   secondary, 3:495  
   therapies for, 3:495t  
   universal recommendations, 3:496  
   WHO diagnostic criteria, 3:507  
 Osteosarcoma, 1:99, 1:242, 3:185  
 Ottonello method, for cervical vertebrae, 1:430-431  
 "Outlet" projection of pelvic bones, 1:385  
 Output phosphor, 3:383  
 Ova, 2:253  
 Ovaries, 2:253  
 Overall risk of fragility fracture, 3:529  
 Over-the-needle cannula, 2:243  
 Ovulation, 2:253  
 Oximetry, 3:128  
 Oxygen saturation, 3:128
- P**
- Pacemaker implantation, 3:124  
 Paget's disease, 1:242, 1:353, 1:408, 1:496, 2:296  
 Palate  
   hard, 2:39  
   soft, 2:39  
 Palatine bones, 2:291  
 Palatography, 2:54  
 Palliation, 3:576  
 Palmar, 1:75  
 Pancreas  
   anatomy of, 2:72-74  
   sectional, 3:155, 3:157



- Pancreas—*cont'd*  
 diagnostic ultrasound of, 3:424-425  
 digestive functions of, 2:71  
 endoscopic retrograde cholangiopancreatography of, 2:114-115  
 exocrine cells of, 2:74  
 sectional anatomy of, 3:155, 3:157  
 Pancreatic duct, 2:74  
 Pancreatic juice, 2:74  
 Panoramic tomography, of mandible, 2:398-399  
 Pantomography  
   equipment for, 2:398  
   of mandible, 2:398-399  
 Paramagnetic, 3:413  
 Parametric image, 3:553  
 Paranasal sinuses. *see also specific sinus*  
   anatomy of, 2:403  
   development of, 2:403  
   functions of, 2:403  
   projections of  
     chart, 2:406  
     lateral, 2:410-411  
     overview, 2:402t  
     in right or left position, 2:410-411  
   tomography of, 3:320t  
 Parathyroid glands, 2:51  
 Parenchyma, 1:533, 3:458  
 Parent, 3:486  
 Parietal, 1:75  
 Parietal bones, 2:281  
 Parietal eminence, 2:281  
 Parietoacanthial projection  
   eye, 2:347  
   facial bones, 2:360-361  
   maxillary sinus, 2:414-417  
   modified, 2:362-363  
 Parietoorbital oblique projection  
   optic canal and foramen, 2:334-335  
   sphenoid strut, 2:302  
 Parotid duct, 2:40  
 Parotid gland  
   anatomy of, 2:40  
   sectional, 3:141  
   projections of  
     lateral, 2:46-47  
     overview, 2:38t  
     in prone position, 2:45  
     in right or left position, 2:46-47  
     in supine position, 2:44  
     tangential, 2:44-45  
   sectional anatomy of, 3:141  
   sialogram of, 2:43  
 Pars interarticularis, 1:402  
 Partial volume averaging, 3:353  
 Particle accelerator, 3:486  
 Patella  
   anatomy of, 1:235  
   Hughston method, 1:331  
   Kuchendorf method, 1:330  
   Merchant method, 1:332-333  
   projections for  
     chart, 1:243  
     lateral, 1:327  
     in lateral rotation, 1:329  
     in medial rotation, 1:328  
     in mediolateral position, 1:327  
     overview, 1:229t  
     PA, 1:326  
     PA axial oblique, 1:330  
     PA oblique, 1:328-329  
     tangential, 1:331-335  
   radiologic imaging of, 1:309  
   Settegast method, 1:334-335  
 Patellofemoral joint  
   overview, 1:229t  
   tangential projection of, 1:331-335  
 Patency, 3:128  
 Patent foramen ovale, 3:128  
 Pathologist, 3:576  
 Patient  
   attire of, 1:20  
   handling of, 1:21  
   ill or injured, handling considerations for, 1:22  
   instructions for, 1:19  
   radiation protection for  
     area shielding, 1:50  
     collimation, 1:50  
     examination determinations, 1:51-52  
     filtration, 1:49  
     image receptors, 1:50  
     patient selection evaluation, 1:51-52  
     radiographic technique, 1:50  
     selection of, 1:51-52  
 Pawlow method, for cervicothoracic region, 1:438-439  
 Peak bone mass, 3:529  
 Pearson method, for AP projection of  
   acromioclavicular articulation, 1:200-201  
 Pectoralis major, 3:145  
 Pediatric imaging  
   abdominal radiography  
     image evaluations, 3:193t  
     immobilization, 3:206-207  
     positioning, 3:206-207  
   age-based approaches  
     adolescents, 3:175  
     overview, 3:173  
     6 months to 2 years old, 3:173  
     2 to 4 years old, 3:174  
     6 to 8 years old, 3:174  
     5 years old, 3:174  
   blood and body fluid precautions, 3:177  
   bone age determinations, 3:209  
   chest radiography  
     centering, 3:190  
     collimation, 3:190  
     description of, 3:189  
     image evaluation, 3:192-3:193t  
     method, 3:190  
     for newborn to 3 years old, 3:189-190  
     supine, 3:192  
     for 3 to 10 year old, 3:191  
     in upright position, 3:189  
   computed tomography, 3:212-213  
   disease- or condition-specific considerations  
     child abuse. *see* Children, abuse of  
     epiglottitis, 3:179  
     gastroschisis, 3:179  
     myelomeningocele, 3:178  
     omphalocele, 3:179  
     osteogenesis imperfecta, 3:179  
   foreign body localization  
     aspirated foreign body, 3:209-210  
     ingested foreign body, 3:210  
   gastrointestinal procedures  
     immobilization for, 3:207-208  
     radiation protection, 3:208  
   genitourinary procedures  
     intravenous urogram, 3:208  
     voiding cystourethrogram, 3:208  
   hip radiography  
     image evaluation, 3:195  
     immobilization, 3:195  
     initial images, 3:194  
     patient positioning, 3:195  
     patient preparation and communication, 3:194  
     principles of, 3:194  
     imaging room, 3:171  
     immobilization, 3:188  
     interventional radiology, 3:214-216  
     isolation protocols, 3:177  
 Pediatric imaging—*cont'd*  
   limb radiography  
     fracture management, 3:204  
     image evaluations, 3:193t, 3:205  
     immobilization, 3:202-203  
     overview, 3:202  
     radiation protection, 3:204  
   magnetic resonance imaging, 3:212  
   myelography, 3:212  
   nuclear medicine, 3:216  
   overview, 3:170  
   parental considerations  
     agitated parents, 3:172  
     participation, 3:172  
   physically and mentally disabled children, 3:175  
   premature infants, 3:178  
   principles of, 3:170  
   protective measures  
     from injury, 3:186  
     from unnecessary radiation, 3:186-188  
   psychologic considerations, 3:175-176  
   scoliosis, 3:211  
   skull radiography  
     description of, 3:196  
     immobilization for, 3:196  
     positioning, 3:198-199  
     protocols for, 3:200t, 3:201  
   three-dimensional imaging, 3:214  
   waiting room, 3:171  
 Pelvic cavity system  
   anatomy of, 2:195  
   retrograde urography of, 2:226-227  
 Pelvic bones  
   Lilienfeld method, 1:386  
   projections of  
     AP axial "outlet," 1:385  
     "inlet," 1:386-387  
     "outlet," 1:385  
     PA, 1:384  
     PA axial "inlet," 1:387  
     superoinferior axial "inlet," 1:386  
   Staanig method, 1:387  
   Taylor method, 1:385  
 Pelvic cavity, 1:350, 2:71  
 Pelvic girdle, 1:345  
 Pelvic kidney, 2:200  
 Pelvic pneumography, 2:260, 2:262  
 Pelvic sacral foramina, 1:404  
 Pelvimetry  
   AP projection, 2:267  
   Colcher-Sussman method, 2:267-268  
   definition of, 2:264  
   description of, 2:266  
   lateral projection, 2:268  
   overview of, 2:252  
 Pelvis  
   anatomy of, 1:345, 1:352  
   articulations of, 1:349-350  
   brim of, 1:350  
   Chassard-Lapiné method, 1:360-361  
   false, 1:350  
   female vs. male, 1:350t  
   fractures of, 2:7t  
   landmarks of, 1:62t, 1:351  
   magnetic resonance imaging of, 3:407  
   mobile radiography of, 3:250-251  
   projections for  
     AP, 1:355-357  
     axial, 1:360-361  
     chart, 1:353  
     lateral, 1:358-359  
     overview, 1:344t  
     in recumbent position, 1:358  
     in right or left position, 1:358-359  
   trauma radiographs, 2:21  
   true, 2:266

- Pencil-beam collimation, 3:529  
 Penetrating trauma, 2:2  
 Percent coefficient of variation, 3:529  
 Percutaneous, 3:128  
 Percutaneous atherectomy, 3:72  
 Percutaneous nephrolithotomy, 3:77, 3:128  
 Percutaneous renal puncture, 2:224-225  
 Percutaneous transhepatic cholangiography, 2:110-111  
 Percutaneous transluminal coronary angioplasty  
   catheters for, 3:69  
   definition of, 3:128  
   description of, 3:68, 3:73, 3:115  
   particulate agents, 3:73t  
   procedure, 3:68-73, 3:115-118  
 Perfusion, 3:411, 3:413  
 Pericardial cavity, 3:22  
 Pericardial sac, 3:22  
 Pericardium, 3:128  
 Periosteum, 1:66  
 Peripheral, 1:75  
 Peripherally inserted central catheters, 3:215  
 Peristalsis, 1:18, 2:128  
 Peritoneal cavity, 2:71, 3:439  
 Peritoneal sac, 2:71  
 Peritoneum  
   parietal, 2:71  
   visceral, 2:71  
 Permanent magnet, 3:414  
 Perpendicular plate of ethmoid, 2:280  
 Petromastoid portion  
   anatomy of, 2:286  
   Arcelin method, 2:440-441  
   Henschen method, 2:434, 2:436  
   Hirtz modification, 2:450  
   Law method  
     modified, 2:432-433  
     original, 2:430-431  
   Lysholm method, 2:434-435, 2:437  
   Mayer method, 2:442-445  
   Owen modifications, 2:444-445  
   projections of  
     in anterior profile, 2:440-441  
     AP axial, 2:446-447  
     axiolateral, 2:434-437  
     axiolateral oblique, 2:430-431, 2:438-445  
     chart, 2:425  
     with double-tube angulation, 2:430-431  
     overview, 2:424t  
     in posterior profile, 2:438-439  
     with single-tube angulation, 2:432-433  
     submentovertical, 2:448-449  
   Schüller method, 2:436  
   Stenvers method, 2:438-439  
   Towne method, 2:446-447  
 Petrous pyramid, 2:286  
 Phalanges  
   anatomy of, 1:230  
   definition of, 1:91  
   radiologic imaging of, 1:274  
 Phantom images, 3:327  
 Pharmaceutical, 3:486  
 Pharyngeal tonsil, 2:52  
 Pharyngography  
   deglutition assessments using, 2:56-57  
   description of, 2:56  
   Gunson method, 2:57  
 Pharynx  
   anatomy of, 2:52  
   function of, 2:52  
   laryngeal, 2:52  
   pharyngography of. *see* Pharyngography  
   projections of  
     AP, 2:64-65  
     lateral, 2:66-67  
     overview, 2:50t  
     in right or left position, 2:66-67  
     sectional anatomy of, 3:137, 3:149  
 Phenergan. *see* Promethazine hydrochloride  
 Phonation tests  
   inspiratory, 2:59  
   normal (expiratory), 2:58  
 Photographic subtraction  
   composite-mask procedure, 3:89  
   definitions, 3:86  
   first-order, 3:87-88  
   indications, 3:86  
   second-order, 3:88-89  
 Photomultiplier tube, 3:486, 3:553  
 Photopenia, 3:486  
 Photostimulable phosphor, 3:370  
 Physicians assistant, 3:267  
 Physiology, 1:58  
 Pia mater, 3:3  
 Picture archive and communication system, 3:367-370, 3:377, 3:383  
 Piezoelectric effect, 3:458  
 Pigg-o-stat, 3:189  
 Pineal body, 3:134, 3:141  
 Pinna, 3:141  
 Piriform recess, 2:52  
 Pisiform  
   anatomy of, 1:91  
   projections of  
     AP, 1:123  
     PA, 1:122  
 Pituitary adenoma, 2:296  
 Pituitary tumor, transsphenoidal resection of, 3:292-293  
 Pivot joint, 1:72-1:73  
 Pixel(s)  
   definition of, 3:353, 3:370, 3:375, 3:383, 3:553  
   shifting of, 3:378, 3:383  
 Placenta, 2:255  
 Placenta previa, 2:255  
 Placentography, 2:264  
 Planigraphic principle, 3:327  
 Plantar, 1:75  
 Pledget, 3:128  
 Pleurae  
   anatomy of, 1:534  
   parietal, 1:534  
   projections of  
     AP, 1:572-573  
     chart, 1:539  
     lateral, 1:574  
     overview, 1:530t  
     in right or left lateral decubitus positions, 1:572-573  
     in ventral or dorsal decubitus positions, 1:574  
 Pleural effusion, 1:538  
 Pluridirectional blurring motions, 3:327  
 Pneumoarthrography, 1:585  
 Pneumoconiosis, 1:538  
 Pneumonia, 1:538  
 Pneumoperitoneum, 2:76  
 Pneumothorax, 1:538, 1:542  
 Pocket ionization chambers, 1:54  
 Polycystic kidney disease, 2:200  
 Polyp, 2:127, 2:296  
 Pons, 3:2, 3:135, 3:139  
 Porta hepatis, 2:72  
 Portal circulation, 3:128  
 Portal hypertension, 3:81  
 Portal system, 3:21  
 Portal vein, 2:72, 3:152-153, 3:155  
 Ports, 3:216  
 Position  
   anteroposterior, 1:9-10  
   decubitus, 1:84  
   definition of, 1:79  
   Fowler's, 1:80-1:81  
   lateral, 1:81  
   left anterior oblique, 1:82  
   lordotic, 1:84  
   oblique, 1:82  
 Position---*cont'd*  
   posteroanterior, 1:9-10  
   projection and, differences between, 1:84  
   prone, 1:80  
   recumbent, 1:80  
   right anterior oblique, 1:82  
   seated, 1:80  
   supine, 1:80  
   Trendelenburg's, 1:80-1:81  
   upright, 1:76, 1:80  
 Positron, 3:553  
 Positron emission tomography  
   central nervous system uses, 3:15-16  
   clinical studies, 3:548-549  
   computed tomography and, 3:477, 3:532-534, 3:533t, 3:552  
   data acquisition, 3:542-545  
   definition of, 3:553  
   future of, 3:551  
   historical development of, 3:534  
   image reconstruction and processing, 3:546-547  
   magnetic resonance imaging and, 3:532-534, 3:533t  
   mobile units, 3:551  
   normal values for, 3:550  
   nuclear medicine use, 3:476  
   overview, 3:532  
   positrons, 3:535-536  
   radiation dosimetry, 3:550  
   radionuclide production, 3:536-539  
   radiopharmaceuticals, 3:540-541  
   single photon emission computed tomography and, 3:532-534, 3:533t  
 Positrons, 3:535-536, 3:536t  
 Posterior, 1:75  
 Posterior cruciate ligament  
   anatomy of, 1:236  
   double-contrast arthrography of, 1:589  
 Posteroanterior position, 1:9-10  
 Posteroanterior projection, 1:76-77  
 Postprocessing, 3:353, 3:383  
 Pott's fracture, 1:242  
 Precession, 3:414  
 Precision, 3:529  
 Preexposure instructions, 1:37  
 Pregnancy  
   caution signs regarding, 1:51  
   diagnostic ultrasound of, 3:443-449  
   radiation protection guidelines, 1:51  
   radiographers, 1:54  
   radiography during  
     cephalometry  
       definition of, 2:264  
       description of, 2:266  
     considerations, 2:264  
     fetography, 2:264-265  
     patient care, 2:264  
     patient preparation, 2:264  
     pelvimetry  
       AP projection, 2:267  
       Colcher-Sussman method, 2:267-268  
       definition of, 2:264  
       description of, 2:266  
       lateral projection, 2:268  
     placentography, 2:264  
     radiation protection, 2:264  
     respiration, 2:264  
   Primary data, 3:353  
   Procedure book, 1:17  
 Projection(s)  
   acanthioparietal  
     of facial bones, 2:364-365  
     for trauma, 2:364-365  
   anteroposterior, 1:76-77  
   axial, 1:77  
   complex, 1:78  
   definition of, 1:76  
   lateral, 1:78

- Projection(s)—cont'd**  
 oblique, 1:78  
 parietoacanthial  
   eye, 2:347  
   facial bones, 2:360-361  
   maxillary sinus, 2:414-417  
   modified, 2:362-363  
 parietoorbital oblique  
   optic canal and foramen, 2:334-335  
   sphenoid strut, 2:302  
 position and, differences between, 1:84  
 posteroanterior, 1:76-77  
 submentovertical  
   cranial base, 2:322-323  
   ethmoidal sinus, 2:418-419  
   jugular foramina, 2:454-455  
   mandible, 2:389  
   petromastoid process, 2:448-449  
   posterior circulation, 3:66-67  
   skull, 3:201  
   sphenoidal sinus, 2:418-419  
   zygomatic arch, 2:372-373  
 tangential, 1:77  
 true, 1:79  
 verticosubmental  
   cranial base, 2:325  
   mandible, 2:390-391  
 view and, differences between, 1:85  
**Projectional technique, 3:529**  
**Promethazine hydrochloride, 2:240t-241t**  
**Pronation, 1:87**  
**Prone position, 1:80**  
**Prophylactic surgery, 3:576**  
**Prostate cancer, 3:571**  
**Prostate gland**  
   anatomy of, 2:199, 2:256  
   function of, 2:199  
   sectional anatomy of, 3:160-161, 3:165  
**Prostatography, 2:228, 2:271**  
**Protocol, 3:353**  
**Proton, 3:463, 3:486**  
**Proton density, 3:388, 3:414**  
**Protuberance, 1:74**  
**Proximal, 1:75**  
**Proximal femur**  
   anatomy of, 1:347-348  
   dual x-ray absorptiometry of, 3:519-520  
**Proximal forearm**  
   in acute flexion, 1:148  
   AP projection of, 1:147  
   PA projection of, 1:148  
**Proximal humerus**  
   anatomy of, 1:94, 1:163  
   Blackett-Healy method  
     for subscapular insertion, 1:199  
     for teres minor insertion, 1:198  
   Fisk modification, 1:196-197  
   overview, 1:160t  
   projections of  
     AP, 1:199  
     AP axial, 1:191  
     PA, 1:198  
   Stryker "notch" method for, 1:191  
   teres minor insertion, 1:198  
**Proximal interphalangeal joint, 1:95, 1:238**  
**Proximal tibiofibular joint, 1:240**  
**Psoas major, 3:152-153, 3:155, 3:157-159**  
**Pterion, 2:277**  
**Pterygoid hamulus, 2:284**  
**Pterygoid processes, 2:284**  
**Pubis, 1:346**  
**Pubis symphysis**  
   anatomy of, 1:349t, 1:350  
   Chamberlain method for abnormal sacroiliac motion, 1:468-469  
   palpation of, 1:351  
   PA projection of, 1:468-469  
**Pubis symphysis—cont'd**  
   radiologic imaging of, 1:356, 1:367, 1:386  
   sectional anatomy of, 3:160-161  
**Pulmonary apex, 1:548-549**  
**Pulmonary apices**  
   Fleischner method, 1:536  
   Lindblom method, 1:566-567  
   projections of  
     AP axial, 1:566-567, 1:570-571  
     chart, 1:539  
     in lordotic position, 1:536, 1:566-567  
     in oblique lordotic position, 1:566-567  
     overview, 1:530t  
     PA axial, 1:536, 1:568-569  
**Pulmonary artery, 3:145, 3:149**  
**Pulmonary circulation, 3:128**  
**Pulmonary edema, 1:538**  
**Pulmonary hilum, 3:311**  
**Pulmonary trunk, 3:145, 3:149**  
**Pulse, 3:24, 3:128, 3:414**  
**Pulse height analyzer, 3:470, 3:486**  
**Pulse sequences, 3:388, 3:414**  
**Pulse wave ultrasound, 3:458**  
**Punctum lacrimale, 2:348**  
**Pyelography, 2:203**  
**Pyelonephritis, 2:200, 2:213**  
**Pyloric sphincter, 2:120**  
**Pyloric stenosis, 2:127, 3:185**  
**Pyrogen free, 3:486**
- Q**  
**Quadratus lumborum muscle, 3:152-153, 3:155**  
**Quantitative computed tomography, 3:489**  
**Quantitative ultrasound, 3:526-527, 3:529**  
**Quantum mottle, 3:187**  
**Quantum noise, 3:353**
- R**  
**Radial artery, 3:47**  
**Radial deviation, 1:129**  
**Radial fossa, 1:94**  
**Radial notch, 1:93**  
**Radial styloid process, 1:93**  
**Radial tuberosity**  
   anatomy of, 1:93  
   AP projection of, 1:139  
**Radiation, 3:463, 3:486**  
**Radiation absorbed dose, 1:43**  
**Radiation dose equivalent, 1:43**  
**Radiation exposure**  
   early injuries secondary to, 1:40  
   guidelines to minimize, 1:53  
   measuring devices for  
     anatomic placement of, 1:54  
     film badge, 1:54  
     pocket ionization chambers, 1:54  
     thermoluminescent dosimetry badges, 1:54  
   occupational  
     description of, 1:49  
     guidelines to minimize, 1:53  
   during pregnancy, 1:51  
   radiographer, 1:49  
   sources of  
     consumer products, 1:44  
     industrial applications, 1:44  
     medical, 1:44, 1:47  
     natural background  
       cosmic, 1:44  
       description of, 1:44  
       internally deposited radionuclides, 1:44  
       terrestrial, 1:44  
     research applications, 1:44  
**Radiation oncology, 3:556, 3:576**  
   brachytherapy, 3:561  
   clinical applications of  
     breast cancer, 3:572  
     cervical cancer, 3:572  
     Hodgkin's disease, 3:572  
     larynx cancer, 3:573  
     lung cancer, 3:571  
     medulloblastoma, 3:573  
     oral cavity cancer, 3:572  
     prostate cancer, 3:571  
     skin cancer, 3:573  
   equipment, 3:561-565  
   external-beam therapy, 3:561  
   future trends in, 3:574  
   historical development of, 3:557  
   principles of, 3:556  
   steps involved in  
     dosimetry, 3:567-569  
     simulation, 3:565-567  
     treatment, 3:570  
   theory of, 3:560  
**Radiation protection**  
   cardinal principles of, 1:53b  
   guidelines  
     basis for, 1:45  
     dose limits, 1:45  
     dose-response relationship, 1:45  
     effective dose equivalent, 1:46  
   patient  
     area shielding, 1:50  
     collimation, 1:50  
     examination determinations, 1:51-52  
     filtration, 1:49  
     image receptors, 1:50  
     patient selection evaluation, 1:51-52  
     radiographic technique, 1:50  
   principles of, 1:53  
   reasons for, 1:42  
**Radiation therapist, 3:556, 3:576**  
**Radiation units**  
   application of, 1:43  
   exposure, 1:43  
   radiation dose, 1:43  
   radiation dose equivalent, 1:43  
   SI, 1:42-1:42t  
**Radical mastectomy, 2:488**  
**Radioactive, 3:486, 3:576**  
**Radioactive detectors**  
   gas-filled, 3:469  
   scintillation, 3:469  
**Radioactivity, 3:463, 3:486**  
**Radioactivity concentration, 3:553**  
**Radiocurable, 3:576**  
**Radiodermatitis, 1:40**  
**Radiofrequency ablation, 3:124**  
**Radiofrequency pulse, 3:414**  
**Radiogrammetry, 3:489, 3:529**  
**Radiograph**  
   anatomic markers, 1:24-25  
   anatomic position  
     anteroposterior, 1:9-1:10  
     definition of, 1:7  
     illustration of, 1:7-8  
     lateral, 1:10-11  
     oblique, 1:12  
     posteroanterior, 1:9-1:10  
   clinical uses of, 1:4  
   display of, 1:7  
   identification of, 1:23  
   positioning terminology, 1:75  
   of spine, 3:5  
   study points for  
     adjacent structures, 1:4  
     contrast, 1:4, 1:6  
     magnification, 1:6



- Radiograph—*cont'd*  
 study points for—*cont'd*  
 optical density, 1:4  
 recorded detail, 1:4, 1:6  
 shape distortion, 1:6  
 superimposition, 1:4
- Radiographer  
 exposure of, 1:49  
 pregnant, 1:54  
 protective methods  
 apparel, 1:52-1:52t  
 guidelines, 1:53  
 radiation monitoring devices  
 film badge, 1:54  
 pocket ionization chamber, 1:54  
 thermoluminescent dosimetry badges, 1:54
- Radiographic absorptiometry, 3:489, 3:525, 3:529
- Radiographic examining room, 1:14
- Radioisotope, 3:553
- Radiologist, 1:13
- Radionuclides  
 creation of, 3:464  
 decay of, 3:463, 3:545  
 definition of, 3:486, 3:553  
 description of, 3:532  
 half-life of, 3:464  
 internally deposited, 1:44  
 for positron emission tomography, 3:536-539  
 production of, 3:536-539
- Radiopaque, 1:20
- Radiopharmaceuticals  
 characteristics of, 3:465, 3:467t  
 definition of, 3:486, 3:554  
 description of, 3:465  
 doses of, 3:466  
 positron emission tomography, 3:540-541  
 production of, 3:540-541  
 types of, 3:467t
- Radiosensitivity, 3:576
- Radiotracer, 3:532, 3:554
- Radium, 3:576
- Radius  
 anatomy of, 1:93  
 articulations of, 1:97  
 head, lateral projection, 1:150-151
- Radon, 1:44
- Rafert-Long method, for scaphoid imaging, 1:132-133
- Rafert modification, for shoulder joint, 1:176-177
- Rapid acquisition recalled echo, 3:414
- Raw data, 3:414
- Ray, 3:554
- Reactor, 3:576
- Real time, 3:353, 3:383
- Real-time imaging, 3:458
- Recommended dose limit, 1:45
- Recorded detail  
 factors that affect, 1:4  
 illustration of, 1:6
- Rectal ampulla, 2:125
- Rectilinear scanner, 3:486
- Rectum, 2:125, 3:160-161, 3:164
- Rectus abdominis, 3:152-153, 3:155, 3:158-159, 3:164
- Recumbent position, 1:80
- Reference population, 3:529
- Reflection, 3:459
- Reflux, 2:127
- Refraction, 3:459
- Regional enteritis, 2:127
- Region of interest  
 definition of, 3:353, 3:530, 3:554  
 in positron emission tomography, 3:545
- Regurgitation, 3:459
- Relative biologic effectiveness, 3:560, 3:576
- Relaxation, 3:414
- Relaxation times, 3:386, 3:414
- rem, 1:43
- Remask, 3:383
- Renal arteriography, 3:42
- Renal cell carcinoma, 2:200
- Renal cortex, 2:197
- Renal fascia, 2:196
- Renal hypertension, 2:200
- Renal medulla, 2:197
- Renal obstruction, 2:200
- Renal papilla, 2:197
- Renal parenchyma  
 definition of, 2:194t
- nephrotomography  
 bolus injection, 2:221  
 contraindications, 2:221  
 contrast media for, 2:221  
 indications, 2:221  
 infusion, 2:221  
 patient preparation, 2:221  
 procedure, 2:222-223
- nephrourography, 2:221
- percutaneous renal puncture, 2:224-225
- Renal pelvis, 2:197
- Renal pyramids, 2:197
- Renal tubules, 2:197
- Renal venography, 3:46
- Rendering, 3:353
- Reperfusion, 3:128
- Reproductive system  
 anatomy of, 2:258
- female  
 ovaries, 2:253  
 radiography  
 hysterosalpingography, 2:260-261  
 intrauterine device localization, 2:269  
 for nonpregnant patients, 2:260-261  
 pelvic pneumography, 2:260, 2:262  
 vaginography, 2:260, 2:262-263
- uterine tubes, 2:253  
 uterus, 2:254  
 vagina, 2:254
- male  
 ductus deferens, 2:256  
 ejaculatory ducts, 2:256  
 overview, 2:256  
 prostate, 2:257  
 radiography of, 2:270-271  
 seminal vesicles, 2:256  
 testes, 2:256
- Research, 1:44
- Resistive magnet, 3:414
- Resolution, 3:459, 3:554
- Resonance, 3:414
- Respiratory distress syndrome, 1:538, 3:185
- Respiratory system  
 aging-related changes, 3:228  
 description of, 1:532
- Restenosis, 3:128
- Restricted area, 3:303
- Retina, 2:343
- Retrieval, 3:353
- Retrograde urography  
 chart for, 2:201  
 contrast media, 2:206-207  
 description of, 2:205  
 history of, 2:206  
 illustration of, 2:207  
 patient preparation, 2:209  
 pelvicalyceal system and ureters evaluation, 2:226-227
- Retroperitoneal cavity, 3:459
- Reverse Waters method, 2:26, 2:364-365
- Rhese method, 2:334-337
- Rheumatoid arthritis, 1:99, 1:168
- Ribs  
 above diaphragm, 1:520  
 anatomy of, 1:490  
 anterior, projections of  
 chart, 1:497  
 considerations, 1:514-515  
 PA, 1:518-519
- axillary  
 AP oblique projection of, 1:522-523  
 chart of projections, 1:497  
 PA oblique projection of, 1:524-525  
 in RAO or LAO position, 1:524-525  
 in RPO or LPO position, 1:522-523
- below diaphragm, 1:520
- floating, 1:490
- number of, 1:490
- posterior, projections of  
 AP, 1:520-521  
 considerations, 1:514-515
- projections of  
 AP, 1:515  
 AP oblique, 1:515, 1:522-523  
 body position considerations, 1:495  
 body positions, 1:514  
 chart, 1:497  
 overview, 1:488t  
 PA, 1:515  
 PA oblique, 1:515  
 in RPO or LPO position, 1:522-523
- during respiration  
 movements, 1:493  
 shallow breathing, 1:516-517  
 suspended respiration, 1:516-517
- trauma  
 considerations for, 1:495  
 fractures, 1:516  
 true, 1:490
- Right anterior oblique position, 1:82
- Right posterior oblique position, 1:83
- Right ventricle, 3:146-147
- Rima glottidis, 2:53
- Road map technique, 3:383
- Robert method, for AP projection of first carpometacarpal joint, 1:108-109
- Rods, 2:343
- Roentgen, 1:43
- Rosenberg method, for knee, 1:315
- Rotation, 1:87
- Rotational burr atherectomy, 3:117, 3:128
- Rotator cuff tear, 1:585
- Round window, 2:289
- Rugae  
 stomach, 2:120  
 urinary bladder, 2:198
- S**
- Sacral cornua, 1:405
- Sacral promontory, 1:404
- Sacral vertebrae, 1:394
- Sacral vertebral canal  
 axial projection of, 1:474-475  
 Nölke method, 1:474-475
- Sacroiliac joints  
 projections of  
 AP axial, 1:462-463  
 AP oblique, 1:464-465  
 chart, 1:409  
 overview, 1:393t  
 PA axial, 1:462-463  
 PA oblique, 1:466-467  
 in RAO and LAO positions, 1:466-467  
 in RPO and LPO positions, 1:464-465  
 radiologic imaging of, 1:349t, 1:350, 1:356
- Sacrum  
 anatomy of, 1:404-405  
 landmarks of, 1:62t

- Sacrum---*cont'd*  
 projections of  
   AP axial, 1:470-471  
   chart, 1:409  
   lateral, 1:472-473  
   overview, 1:393t  
   PA axial, 1:470-471  
   in right or left position, 1:472-473  
 sectional anatomy of, 3:164
- Saddle joint, 1:72-1:73
- Sagittal plane, 1:58-1:59
- Salivary duct obstruction, 2:42
- Salivary glands  
 anatomy of, 2:40-41  
 digestive functions of, 2:71  
 parotid  
   anatomy of, 2:40  
   projections of  
     lateral, 2:46-47  
     overview, 2:38t  
     in prone position, 2:45  
     in right or left position, 2:46-47  
     in supine position, 2:44  
     tangential, 2:44-45  
   sialogram of, 2:43  
 sublingual  
   intraoral method, 2:48  
   projections of  
     axial, 2:48  
     overview, 2:38t  
 submandibular  
   anatomy of, 2:40  
   intraoral method, 2:48  
   projections of  
     axial, 2:48  
     lateral, 2:46-47  
     overview, 2:38t  
     in right or left position, 2:46-47  
   sialogram of, 2:42
- Sarcoidosis, 1:538
- Scan, 3:353, 3:459
- Scan diameter, 3:353
- Scan duration, 3:353
- Scan time, 3:353
- Scaphoid  
 anatomy of, 1:91, 1:96  
 projections of  
   AP, 1:123  
   PA, 1:122  
   PA axial  
     Rafert-Long method, 1:132-133  
     Stecher method, 1:130-131
- Scapula  
 anatomy of, 1:162-163  
 sectional, 3:145  
 articulations of, 1:165  
 Lilienfeld method for, 1:216-217  
 Lorenz method for, 1:216-217  
 muscles of, 1:166  
 projections for  
   AP, 1:212-213  
   AP oblique, 1:218-219  
   chart for, 1:168  
   lateral, 1:214-215  
   overview, 1:160t  
   PA oblique, 1:216-217  
   in RAO or LAO position, 1:214-217  
   in RPO or LPO position, 1:218-219  
 sectional anatomy of, 3:145
- Scapular spine  
 Laquerrière-Pierquin method for, 1:222-223  
 projections for, 1:219  
 overview, 1:160t  
 in prone position, 1:224-225  
 tangential, 1:222-225
- Scapulohumeral articulation, 1:164
- Scattering, 3:459
- Scatter radiation, 1:52
- Scheuermann's disease, 1:408, 3:185
- Schüller method  
 for cranial base imaging, 2:322-325  
 for petromastoid portion imaging, 2:436
- Scintillate, 3:486
- Scintillation camera, 3:462, 3:486
- Scintillation counter, 3:530
- Scintillation detector, 3:469, 3:486
- Scintillators, 3:534, 3:554
- Sclera, 2:343
- Scoliosis  
 definition of, 1:395, 1:408  
 description of, 1:478  
 Ferguson method, 1:480-481  
 projections of  
   AP, 1:478-481  
   chart, 1:409  
   considerations for, 1:478-479  
   lateral, 1:478  
   overview, 1:393t  
   PA, 1:478-481
- Sectional plane, 3:459
- Section thickness, 3:327
- Segmentation, 3:353
- Segmented region, 3:554
- Seldinger technique, for catheterization, 3:30-31
- Sella turcica  
 anatomy of, 2:283, 2:357  
 projections of  
   AP axial, 2:328-329  
   chart, 2:297  
   lateral, 2:326-327  
   overview, 2:274t  
   PA axial, 2:302, 2:321, 2:330-331  
   in right or left position, 2:326-327  
 tomography of, 3:320t, 3:323  
 Valdin method, 2:302
- Semicircular canals, 2:289
- Semiconductor, 3:383
- Seminal ducts, 2:252, 2:270-271
- Seminal vesicles, 2:256
- Semi-restricted area, 3:303
- Sensitivity, 3:554
- Septa, 3:554
- Septum pellucidum, 3:134, 3:140
- Serial imaging, 3:128
- Serratus anterior muscle, 3:146-147
- Sesamoid bones  
 anatomy of, 1:70, 1:232  
 Causton method for, 1:254-255  
 Lewis and Holly method for, 1:252-253  
 tangential projection, 1:252-255
- Settegast method, for patella and patellofemoral joint, 1:334-335
- Shaded surface display, 3:353
- Shading, 3:353
- Shadow shield, 1:31-32
- Shewhart control chart rules, 3:530
- Shielding  
 area, for patient protection, 1:50  
 gonadal, 1:31-32, 1:50
- Shock, 2:7t
- Short bones, 1:68
- Shoulder girdle  
 anatomy of, 1:161  
 articulations of  
   acromioclavicular, 1:165, 1:167  
   overview, 1:164t  
   scapulohumeral, 1:164-166  
   sternoclavicular, 1:165  
 overview, 1:160t  
 projections for  
   AP, 1:169-173  
   with externally rotated humerus, 1:170-1:170t, 1:172
- Shoulder girdle---*cont'd*  
 projections for---*cont'd*  
   with internally rotated humerus, 1:170t, 1:171-173  
   with neutrally rotated humerus, 1:170, 1:172  
   overview, 1:160t  
   radiation protection, 1:169  
   transsthoracic lateral, 1:174-175
- Shoulder joint  
 anatomy of, 1:167  
 Apple method, 1:192-195  
 contrast arthrography of, 1:592-593  
 Garth method, 1:194-195  
 Grashey method, 1:188-189  
 Lawrence method  
   for inferosuperior axial projection, 1:176  
   for transthoracic lateral projection, 1:174-175  
 magnetic resonance imaging of, 1:165  
 mobile radiography of, 3:301  
 Neer method for, 1:190  
 pathology of, 1:168  
 projections for  
   AP axial, 1:168, 1:184  
   AP axial oblique, 1:194-195  
   axial, 1:169  
   chart for, 1:168  
   Cleaves method, 1:169  
   inferosuperior axial  
     with Clements modification, 1:180-181  
     with Lawrence method, 1:176-177  
     with Rafert modification, 1:176-177  
     with West Point method, 1:178-179  
   PA oblique, 1:185-187  
   Rafert modification, 1:176-177  
   in RPO or LPO position, 1:192-195  
   scapular Y, 1:185-187  
   superoinferior axial, 1:182-183  
   tangential, 1:190  
   trauma positioning, 2:28
- Sialography  
 contrast agent use, 2:43  
 description of, 2:42  
 parotid gland, 2:42  
 procedure for, 2:43  
 submandibular gland, 2:42
- Sievert, 1:43, 3:530
- Sigmoid colon, 3:165
- Sigmoid sinus, 3:136
- Signal, 3:414
- Silicosis, 1:538
- Simulator, 3:576
- Single-energy x-ray absorptiometry, 3:484, 3:530
- Single photon absorptiometry, 3:490, 3:530
- Single-photon emission computed tomography  
 brain, 3:480  
 clinical uses, 3:475  
 definition of, 3:486, 3:554  
 description of, 3:15, 3:471  
 nuclear medicine uses, 3:475  
 positron emission tomography and, comparison between, 3:532-534, 3:533t
- Sinus  
 definition of, 1:74  
 ethmoidal  
   anatomy of, 2:280, 2:404, 2:406  
   sectional, 3:136  
 Caldwell method, 2:412-413  
 open-mouth Waters method, 2:416-417  
 projections of  
   chart, 2:406  
   PA, 2:420  
   PA axial, 2:412-413  
   parietoacanthial, 2:416-417  
   submentovertical, 2:418-419  
   technical considerations, 2:407-409  
 sectional anatomy of, 3:136

- Sinus—*cont'd*  
 frontal  
   anatomy of, 2:279, 2:404, 2:406  
   sectional, 3:135  
   Caldwell method, 2:412-413  
   computed tomography of, 2:404-405  
   projections of  
     chart, 2:406  
     PA axial, 2:412-413  
     technical considerations, 2:407-409  
   radiologic imaging of, 2:357  
   sectional anatomy of, 3:135  
 maxillary  
   anatomy of, 2:403  
   description of, 2:290, 2:357  
   development of, 2:403  
   projections of  
     chart, 2:406  
     PA, 2:422  
     parietoacanthial, 2:414-417  
     technical considerations, 2:407-409  
   projections of, 2:407-409  
   radiologic procedure for, 2:90  
 sphenoidal  
   anatomy of, 2:406  
   description of, 2:283  
   projections of  
     PA, 2:421  
     submentovertical, 2:418-419  
 Sinusitis, 2:296  
 SI radiation units, 1:42t, 1:42-43  
 Skeleton  
   appendicular  
     components of, 1:66t  
     functions of, 1:66  
     schematic representation of, 1:67  
   axial  
     components of, 1:66t  
     functions of, 1:66  
     schematic representation of, 1:67  
   bone densitometry measurements, 3:522-524  
   functions of, 3:491  
 Skin  
   aging-related changes, 3:225  
   care of, 3:230  
   dose limit for, 1:46  
   entrance skin exposure  
     definition of, 1:47-1:47t  
     measurement methods, 1:47  
 Skin cancer, 3:573  
 Skin-sparing effect, 3:562, 3:576  
 Skull  
   anatomy of, 2:294-295  
   base of, 3:320t  
   bones of, 2:275-277  
   brachycephalic, 2:299  
   dolichocephalic, 2:299  
   entrance skin exposure for, 1:48t  
   joints of, 2:293t  
   landmarks of, 2:298  
   mesocephalic, 2:299  
   morphology of, 2:299-300  
   radiographic considerations  
     body position, 2:301-303  
     cleanliness, 2:302  
     radiation protection, 2:302  
   sutures of, 2:277  
   tomography of, 3:322  
   topography of, 2:298  
 Slice, 3:353, 3:414  
 Slipped epiphysis, 1:353, 3:185  
 Slip ring, 3:353  
 Small intestine  
   anatomy of, 2:122-123  
   sectional, 3:158-159  
   complete reflux examination of, 2:161  
 Small intestine—*cont'd*  
   divisions of, 2:123  
   enteroclysis of, 2:161  
   fistula of, 2:90  
   gastrointestinal intubation examination of, 2:162-163  
   peristalsis, 2:128  
   projections of  
     AP, 2:158-160  
     chart, 2:126  
     overview, 2:118t  
     PA, 2:158-159  
   radiologic examination of  
     barium administration, 2:157  
     patient positioning, 2:157  
     preparations, 2:157  
   sectional anatomy of, 3:158-159  
 Smith and Abel method, for dens, 1:413  
 Smith's fracture, 1:99  
 Soft palate  
   palatography of, 2:54  
   projections of  
     lateral, 2:66-67  
     overview, 2:50t  
     in right or left position, 2:66-67  
 Somatic effects, of radiation exposure, 1:41  
 Sonar, 3:459  
 Sonic window, 3:459  
 Source-to-image receptor distance  
   description of, 1:6, 1:29-30, 3:29  
   mobile radiography, 3:237  
 Source-to-skin distance, 1:30  
 Spatial frequency response, 3:370  
 Spatial resolution, 3:353, 3:370  
 Spectroscopy, 3:414  
 Spermatic cord, 3:160-161  
 Sphenoidal sinus  
   anatomy of, 2:406  
   sectional, 3:136, 3:139-3:140  
   description of, 2:283  
   projections of  
     PA, 2:421  
     submentovertical, 2:418-419  
 Sphenoid bone, 2:282-284  
 Sphenoid strut  
   Hough method, 2:302  
   parietoorbital oblique projection of, 2:302  
 Sphincter of the hepatopancreatic ampulla, 2:73  
 Spina bifida, 1:396, 1:408  
 Spinal cord  
   anatomy of, 3:3  
   computed tomography of, 3:11  
   magnetic resonance imaging of, 3:12, 3:405  
   sectional anatomy of, 3:149, 3:152-153  
   transverse section of, 3:3  
 Spinal fusion projections  
   AP, 1:482-483  
   in hyperflexion and hyperextension positions, 1:484-485  
   lateral, 1:484-485  
   overview, 1:393t  
   in right or left bending positions, 1:482-483  
 Spin echo, 3:414  
 Spin-lattice relaxation, 3:414  
 Spin-spin relaxation, 3:388, 3:414  
 Spleen  
   anatomy of, 2:74  
   diagnostic ultrasound of, 3:422  
   nuclear medicine scans, 3:482  
   sectional anatomy of, 3:151-153  
 Splenic artery  
   arteriograms of, 3:40  
   sectional anatomy of, 3:152-153  
 Split cassette, for computed radiography, 1:34  
 Spondylolisthesis, 1:403, 1:408  
 Spondylolysis, 1:403, 1:408  
 Spongy bone, 1:66  
 Spot compression, for mammography, 2:495  
 Standard deviation, 3:530  
 Stapes, 2:289  
 Stecher method, for scaphoid imaging, 1:130-131  
 Stenosis, 2:42, 2:200, 3:128  
 Stent, 3:128  
 Stenvers method, for petromastoid portion imaging, 2:438-439  
 Stereotactic surgery  
   central nervous system uses, 3:16  
   computed tomography and, 3:17  
   definition of, 3:16  
   magnetic resonance imaging and, 3:17  
 Stereotaxis  
   definition of, 2:524  
   nonpalpable breast masses, 2:524-527  
 Stereotrophic surgery  
   central nervous system uses, 3:16  
   definition of, 3:16  
 Sterile, 3:303  
 Sternal extremity, 1:161  
 Sternoclavicular articulations  
   anatomy of, 1:167, 1:491  
   body rotation method, 1:509  
   central ray angulation method, 1:510-511  
   Kurzbaumer method, 1:512-513  
   projections of  
     axiolateral, 1:512-513  
     chart, 1:497  
     overview, 1:488t  
     PA, 1:508  
     PA oblique, 1:509-511  
     in RAO or LAO position, 1:509  
 Sternocleidomastoid muscle, 3:138, 3:141, 3:149  
 Sternum  
   anatomy of, 1:489-490  
   Moore method, 1:502-503  
   projections of  
     chart, 1:497  
     considerations for, 1:498  
     lateral, 1:504-507  
     in modified prone position, 1:502-503  
     overview, 1:488t  
     PA oblique, 1:499-503  
     in RAO and LAO positions, 1:499-501  
     in recumbent position, 1:506-507  
     in right or left position, 1:504-507  
     in upright position, 1:504-505  
     in women, 1:498  
   sectional anatomy of, 3:145-147  
   thickness of, effect on central ray angulation, 1:498t  
 Sthenic body habitus, 1:63-64, 1:64t  
 Stochastic effects of radiation exposure, 1:41-42  
 Stomach  
   anatomy of, 2:120-122  
   sectional, 3:151-153, 3:155, 3:157  
   body habitus and, 2:121  
   contrast studies of  
     biphasic examination, 2:141  
     double-contrast, 2:140  
     hypotonic duodenography, 2:141  
     patient positioning for, 2:139  
     single-contrast, 2:139  
   digestive functions of, 2:121  
   fluoroscopy of, 2:139  
   gastrointestinal series, 2:138  
   mucosal studies, 2:156  
   projections of  
     AP, 2:126, 2:152-153  
     AP oblique, 2:148-149  
     chart, 2:126  
     lateral, 2:126, 2:150-151  
     overview, 2:118t  
     PA, 2:126, 2:142-143



- Stomach—*cont'd***  
 projections of—*cont'd*  
   PA axial, 2:126, 2:144-145  
   PA oblique, 2:146-147, 2:154-156  
     in right position, 2:150-151  
   sectional anatomy of, 3:151-153, 3:155, 3:157  
   superior, PA oblique projection of, 2:154-155  
   Wolf method, 2:154-155  
 Streak artifact, definition of, 3:353  
 Strike-through, 3:303  
 Stryker “notch” method, for AP axial projection of humerus, 1:191  
**Styloid process**  
 anatomy of, 2:286  
 Cahoon method, 2:452-453  
 definition of, 1:74  
 Fuchs method, 2:426  
 projections of  
   AP, 2:426  
   AP oblique, 2:426  
   axiolateral oblique, 2:426  
   overview, 2:424t  
   PA axial, 2:452-453  
 Wigby-Taylor method, 2:426  
**Subacromial bursa**, 1:164  
**Subarachnoid space**, 3:3, 3:11  
**Subclavian artery**, 3:143, 3:149  
**Subdural space**, 3:3  
**Sublingual duct**, 2:41  
**Sublingual fold**, 2:39  
**Sublingual gland**  
 intraoral method, 2:48  
 projections of  
   axial, 2:48  
   overview, 2:38t  
**Sublingual space**, 2:39  
**Subluxation**, 1:408  
**Submandibular duct**, 2:40  
**Submandibular gland**  
 anatomy of, 2:40  
   sectional, 3:140  
 intraoral method, 2:48  
 projections of  
   axial, 2:48  
   lateral, 2:46-47  
   overview, 2:38t  
   in right or left position, 2:46-47  
 sectional anatomy of, 3:140  
 sialogram of, 2:42  
**Submentovertical projection**  
 cranial base, 2:322-323  
 ethmoidal sinus, 2:418-419  
 jugular foramina, 2:454-455  
 mandible, 2:389  
 petromastoid process, 2:448-449  
 posterior circulation, 3:66-67  
 skull, 3:201  
 sphenoidal sinus, 2:418-419  
 zygomatic arch, 2:372-373  
**Subscapular fossa**, 1:162  
**Subtalar joint**  
 anatomy of, 1:240  
 Broden method, 1:285-287  
 Isherwood method, 1:289-290  
 projections for  
   AP axial oblique, 1:285-286, 1:289-290  
   in lateral rotation, 1:284, 1:287, 1:290  
   lateromedial oblique, 1:289  
   in medial rotation, 1:285-286  
   medial rotation ankle, 1:289  
   medial rotation foot, 1:289  
   overview, 1:228t  
   PA axial oblique, 1:284  
**Subtracted**, 3:383  
**Subtraction technique**, 3:530  
**Sulcus**, 1:74  
**Sulcus tali**, 1:231  
**Superciliary arches**, 2:279  
**Superconductive magnet**, 3:414  
**Superficial**, 1:75  
**Superior**, 1:75  
**Superior mesenteric artery**  
 arteriograms of, 3:41  
 sectional anatomy of, 3:155, 3:157  
**Superior nasal conchae**, 2:280  
**Superior orbital sulci**  
 anatomy of, 2:333  
 projections of  
   overview, 2:274t  
   PA axial, 2:338-339  
**Superior vena cava**, 3:22, 3:43, 3:145  
**Superparamagnetic**, 3:414  
**Superselective**, 3:383  
**Supination**, 1:87  
**Supine position**, 1:80  
**Supraorbital foramen**, 2:279  
**Supraorbital margins**, 2:279  
**Suprarenal glands**  
 anatomy of, 2:195  
 imaging of, 2:195  
 sectional anatomy of, 3:152-153  
**Supraspinatus muscle**, 3:143  
**Supraspinous fossa**, 1:162  
**Surface landmarks**  
 head and neck, 1:62  
 spine, 1:62t  
 torso, 1:62  
**Surgeon**, 3:267  
**Surgical assistant**, 3:267  
**Surgical attire**, 3:268-269  
**Surgical bed**, 3:576  
**Surgical dressings**, 1:20  
**Surgical radiology**  
 aseptic techniques, 3:273b  
 cannulated hip screws, 3:282-284  
 cervical spine, 3:279  
 chest, 3:278  
 description of, 3:266  
 equipment  
   cleaning of, 3:275  
   description of, 3:274  
 femoral arteriogram, 3:294-295  
 femur nail, 3:285-287  
 hip, 3:282-284  
 hip pinning, 3:282-284  
 humerus, 3:290-291  
 lumbar spine, 3:280-281  
 mobile radiography procedures  
   cervical spine, 3:296-297  
   extremities, 3:300-302  
   hip, 3:300  
   knee, 3:300  
   lumbar spine, 3:298-299  
   shoulder joint, 3:301  
   thoracic spine, 3:298-299  
   tibia, 3:301  
 operative cholangiography, 3:276-277  
 pituitary tumor, transsphenoidal resection of, 3:292-293  
 scope of, 3:266b  
 sterility  
   aseptic techniques, 3:273b  
   interventional radiology considerations, 3:271-272  
   maintenance of, 3:270  
 surgical team  
   attire for, 3:268-269  
   members of, 3:266-267  
   personal hygiene of, 3:269  
 tibial arteriogram, 3:294-295  
 tibia nail, 3:288-289  
 transsphenoidal resection of pituitary tumor, 3:292-293  
**Suspensory muscle of the duodenum**, 2:123  
**Sutures**  
 coronal, 2:277  
 definition of, 1:71  
 lambdoidal, 2:277  
 sagittal, 2:277  
 squamosal, 2:277  
**Symphysis**, 1:71  
**Symphysis pubis**  
 anatomy of, 1:349t, 1:350  
 Chamberlain method for abnormal sacroiliac motion, 1:468-469  
 palpation of, 1:351  
 PA projection of, 1:468-469  
 radiologic imaging of, 1:356, 1:367, 1:386  
 sectional anatomy of, 3:160-161  
**Synchondrosis**, 1:71  
**Syndesmosis**, 1:71  
**Synovial fluid**, 1:72  
**Synovial joints**  
 anatomy of, 1:72  
 types of  
   ball and socket, 1:72-73  
   ellipsoid, 1:72-73  
   gliding, 1:72-73, 1:96  
   hinge, 1:72-73, 1:96  
   pivot, 1:72-73, 1:97  
   saddle, 1:72-73, 1:96  
**Systemic**, 3:576  
**Systemic circulation**, 3:128  
**System noise**, 3:353  
**Systole**, 3:128  
**T**  
**T1**, 3:414  
**T2**, 3:414  
**Table increments**, 3:353  
**Table speed**, 3:353  
**Tabletop output intensity**, 1:47  
**Tachyarrhythmia**, 3:128  
**Tachycardia**, 3:128  
**Taenia coli**, 2:124  
**Talus**  
 anatomy of, 1:231  
 radiologic imaging of, 1:274  
**Tangential projection**, 1:77. *see also specific anatomy, projections for*  
**Target**, 3:554  
**Tarrant method**, for clavicle tangential projection, 1:210-211  
**Tarsals**, 1:231  
**Tarsometatarsal joint**, 1:266  
**Taylor method**, for pelvic bones, 1:385  
**Teamwork**, 3:303  
**Technetium-<sup>99m</sup>Tc**  
 clinical uses, 3:466  
 description of, 3:465  
 for exercise radionuclide angiography, 3:479  
 macroaggregated albumin lung perfusion scan, 3:483  
 for thyroid scan, 3:481  
**Technetium-<sup>99m</sup>Tc mertiatide**, 3:482  
**Technetium-<sup>99m</sup>Tc sestamibi**, 3:480  
**Teeth**, 2:39  
**Teleradiography**, 3:370  
**Teletherapy**, 3:576  
**Temporal bone**  
 anatomy of, 2:286-287  
 hypoglossal canal  
   Miller method, 2:456-457  
 projections of  
   in anterior profile, 2:456-457  
   axiolateral oblique, 2:456-457  
   overview, 2:424t  
 jugular foramina  
   Chaussé II method, 2:426  
   Eraso modification, 2:454-455

- Temporal bone—*cont'd*  
 jugular foramina—*cont'd*  
 Kemp Harper method, 2:454-455  
 projections of  
 AP axial, 2:426  
 overview, 2:424t  
 submentovertical axial, 2:454-455  
 mastoid process  
 Hickey method, 2:426  
 projections of  
 AP tangential, 2:426  
 general procedures, 2:427-429  
 overview, 2:424t  
 PA tangential, 2:426  
 radiation protection, 2:426  
 styloid process  
 anatomy of, 2:286  
 Cahoon method, 2:452-453  
 Fuchs method, 2:426  
 projections of  
 AP, 2:426  
 AP oblique, 2:426  
 axiolateral oblique, 2:426  
 overview, 2:424t  
 PA axial, 2:452-453  
 Wigby-Taylor method, 2:426  
 Temporal process, 2:291  
 Temporomandibular joint  
 contrast arthrography of, 1:594-595  
 projections of  
 AP axial, 2:392-393  
 axiolateral, 2:394-395  
 axiolateral oblique, 2:396-397  
 chart, 2:353  
 overview, 2:352t  
 in right or left positions, 2:394-397  
 radiologic imaging of, 2:307  
 Temporomandibular joint syndrome, 2:296  
 Tendonitis, 1:168  
 Tentorium cerebelli, 3:136  
 Teres minor, PA proximal humerus projection for, 1:198  
 Terminology  
 body movement, 1:86-87  
 medical, 1:88  
 Terrestrial radiation, 1:44  
 Tesla, 3:414  
 Teslascan, 3:400  
 Testes, 2:256, 3:164  
 Teufel method, for acetabulum, 1:380-381  
 Thalamus, 3:134, 3:141  
 Thallium-201  
 myocardial perfusion study, 3:479  
 radiopharmaceutical use, 3:467t  
 Thermoluminescent dosimetry badges, 1:54  
 Third ventricle, 3:2, 3:4, 3:139-3:141  
 Thoracic aortography, 3:33  
 Thoracic cavity  
 anatomy of, 1:60 1:537, 1:531  
 exposure factors for, 1:542  
 technical procedure for, 1:542-543  
 Thoracic duct, 3:24  
 Thoracic vertebrae  
 anatomy of, 1:394, 1:400-401  
 sectional, 3:142-149  
 entrance skin exposure for, 1:48t  
 landmarks of, 1:62t  
 mobile radiography of, in operating room, 3:298-299  
 operating room imaging of, 3:298-299  
 projections of  
 AP, 1:440-441  
 chart, 1:409  
 lateral, 1:442-444  
 oblique, 1:486  
 overview, 1:393t  
 Thoracic vertebrae—*cont'd*  
 projections of—*cont'd*  
 in right or left position, 1:442-444  
 in supine position, 1:440  
 in upright position, 1:440  
 sectional anatomy of, 3:142-149  
 tomography of, 3:320t  
 trauma radiographs, 2:15  
 zygapophyseal joints of, 1:401  
 Thorax  
 anatomy of, 1:489  
 functions of, 1:489  
 joints of, 1:491t  
 Threshold value, 3:353  
 Thrombogenesis, 3:73, 3:128  
 Thrombolytic, 3:128  
 Thrombosis, 3:128  
 Throughput, 3:370  
 Through transmission, 3:459  
 Thumb  
 overview, 1:90t  
 projections  
 AP, 1:106  
 Folio method, 1:112-113  
 lateral, 1:106  
 PA, 1:106, 1:112-113  
 PA oblique, 1:107  
 Thymosin, 1:536  
 Thymus gland, 1:536  
 Thyroid cartilage, 2:52, 3:138  
 Thyroid gland  
 anatomy of, 2:51  
 AP projections of, 2:62-63  
 radiologic examination of, 2:62-63  
 sectional anatomy of, 3:143  
 Tibia  
 anatomy of, 1:232-233  
 arteriography of, 3:294-295  
 mobile radiography of, 3:301  
 nailing of, 3:288-289  
 operative radiology of, 3:288-289  
 projections for  
 AP, 1:303  
 lateral, 1:304-305  
 surgical radiology of, 3:288-289  
 Tibial collateral ligament, 1:236  
 Tibial tuberosity, 1:232  
 Tilt, 1:87  
 Titterington method, for zygomatic arch imaging, 2:354  
 Toes  
 anatomy of, 1:230  
 fifth, 1:250-251  
 fourth, 1:250-251  
 great, 1:249  
 projections for  
 AP, 1:244-245  
 AP axial, 1:244-245  
 AP oblique, 1:247  
 chart, 1:243  
 lateral, 1:249-251  
 lateromedial, 1:249-251  
 medial rotation, 1:247-248  
 mediolateral, 1:249-251  
 overview, 1:228t  
 PA, 1:246  
 PA oblique, 1:248  
 second, 1:249, 1:251  
 third, 1:250-251  
 Tomography  
 blurring motions, 3:327  
 clinical applications of  
 abdominal structures, 3:314-317  
 bone lesions, 3:312  
 fractures  
 healing, 3:314  
 known types, 3:313  
 occult, 3:313  
 Tomography—*cont'd*  
 clinical applications of—*cont'd*  
 intravenous cholangiograms, 3:316-317  
 kidneys, 3:315  
 pathologic processes in soft tissues, 3:308-310  
 pulmonary hila, 3:311  
 soft tissue neoplasms, 3:311  
 computed, *see* Computed tomography  
 disadvantages of, 3:5  
 historical development of, 3:306  
 immobilization techniques for, 3:319  
 positioning for, 3:318, 3:320t-321t  
 positron emission, *see* Positron emission tomography  
 renal, 3:315  
 rules for, 3:322  
 scout, 3:319  
 of skull, 3:322  
 summary overview of, 3:326-327  
 Tomolaryngography, 2:59  
 Tongue  
 anatomy of, 2:39  
 sectional anatomy of, 3:139, 3:149  
 Tonsil  
 anatomy of, 2:39  
 pharyngeal, 2:52  
 Torus fracture, 1:99, 3:185  
 Towne method  
 for cranial imaging, 2:24-25, 2:314-319  
 modified, for zygomatic arches, 2:378-379  
 for petromastoid portion imaging, 2:446-447  
 Trabeculae, 1:66-1:67  
 Trabecular bone, 3:530  
 Tracer, 3:462, 3:486  
 Trachea  
 anatomy of, 1:532  
 projections of  
 AP, 1:544-545  
 axiolateral, 1:548-549  
 lateral, 1:546-547  
 overview, 1:530t  
 in right or left position, 1:546-547  
 sectional anatomy of, 3:143, 3:149  
 Twining method, 1:548-549  
 Tragus, 2:289  
 Transcatheter embolization, 3:73-75  
 Transducer, 3:128, 3:459  
 Transesophageal transducer, 3:576  
 Transjugular intrahepatic portosystemic shunt, 3:81  
 Transluminal extraction atherectomy, 3:117-118, 3:128  
 Transmission scan, 3:554  
 Transsphenoidal resection of pituitary tumor, 3:292-293  
 Transthoracic projection  
 characteristics of, 1:168  
 description of, 1:78  
 Transverse atlantal ligament, 1:397  
 Transverse foramina, 1:398  
 Trapezium, projections of  
 AP, 1:123  
 PA, 1:122  
 PA axial oblique, 1:134  
 Trapezium, 1:92, 3:143, 3:146-147  
 Trapezoid  
 anatomy of, 1:92  
 projections of  
 AP, 1:123  
 PA, 1:122  
 Trauma  
 abdomen  
 AP projection, 2:18-20  
 left lateral decubitus position, 2:20  
 blunt, 2:2  
 central nervous system, 3:5

- Trauma—*cont'd*  
 cervical spine  
   AP axial oblique projection, 2:14  
   AP axial projection, 2:13  
   dorsal decubitus, 2:11-12  
   lateral projection, 2:11-12  
 chest imaging, 2:16-17  
 cranium  
   AP axial projection, 2:24-25  
   AP projection, 2:24-25  
   dorsal decubitus position, 2:22-23  
   lateral projection, 2:22-23  
   Towne method, 2:24-25  
 cystography for, 2:34  
   definition of, 2:2  
   facial bones, 2:26, 2:364-365  
   intravenous urography for, 2:34  
   lower limb imaging, 2:30-32  
   pelvis imaging, 2:21  
   penetrating, 2:2  
 radiography  
   acanthioparietal projection, 2:364-365  
   breathing instructions during, 2:9  
   description of, 2:2  
   documentation, 2:10  
   equipment for, 2:3  
   exposure factors, 2:4  
   image evaluation, 2:10  
   image receptor size, 2:10  
   immobilization devices used during, 2:10  
   patient care, 2:6-2:7t  
   patient positioning for, 2:4-5  
   patient preparation, 2:9  
   positioning aids for, 2:3  
   practices used in, 2:8  
   procedures, 2:9-10  
   radiation protection guidelines, 2:6  
   radiographer's role, 2:5  
   status changes during, 2:7t  
   thoracic spine, 2:15  
   upper limb imaging, 2:27-29  
 Trauma center, 2:2  
 Treatment field, 3:576  
 Trendelenburg's position, 1:80-1:81  
 Trigone, 2:198  
 Tripod fracture, 2:296  
 Triquetrum  
   anatomy of, 1:91, 1:96  
   projections of  
     AP, 1:123  
     PA, 1:122  
 Trochanter, 1:74  
 Trochlea, 1:94  
 Trochlear notch, 1:93  
 True projection, 1:79  
 T-scores, 3:507, 3:530  
 Tubercles, 1:66, 1:74  
 Tuberculosis, 1:538  
 Tuberculum sellae, 2:283  
 Tuberosity, 1:74  
 Tumor, 1:99, 1:168  
 Twinning method  
   for cervicothoracic region, 1:436-437  
   for trachea, 1:548-549  
 Tympanic cavity, 2:289  
 Tympanic membrane, 2:289
- U**
- Ulcerative colitis, 2:76, 2:127  
 Ulna, 1:93  
 Ulnar deviation, 1:128, 1:132-133  
 Ulnar styloid process, 1:93  
 Ultrasound, diagnostic  
   advantages of, 3:416  
   anatomic relationships, 3:419  
   Ultrasound, diagnostic—*cont'd*  
     cardiologic applications of  
       cardiac pathology, 3:454-456  
       congenital heart lesions, 3:456  
       echocardiography, 3:452-453  
       myocardial infarction, 3:455  
       overview, 3:452  
     clinical applications of  
       abdomen, 3:419-422  
       gallbladder, 3:426-427, 3:433  
       kidneys, 3:428-432  
       liver, 3:422-423  
       pancreas, 3:424-425  
       pelvis, 3:438-440  
       retroperitoneum, 3:419-437  
       spleen, 3:422  
       superficial structures, 3:434-435  
       testicles, 3:435  
     color flow Doppler, 3:419  
     definition of, 3:459  
     Doppler effect, 3:419  
     endovaginal, 3:440, 3:443  
     gynecologic applications of, 3:438-442  
     historical development of, 3:417  
     neonatal neurosonography, 3:436-437  
     obstetric applications of, 3:443-449  
     physical principles of, 3:417-419  
     principles of, 3:416  
     quantitative, 3:526-527  
     real-time imaging, 3:419  
     resource organizations for, 3:416  
     sonographer for, 3:416  
     sound wave properties  
       acoustic impedance, 3:417  
       overview, 3:417  
       velocity, 3:418  
     vascular applications of, 3:450-451  
 Umbilical cord, 3:445  
 Umbrella, 3:128  
 Undifferentiation, 3:576  
 Unidirectional tomographic motions, 3:327  
 Universal precautions, 1:15  
 Unrestricted area, 3:303  
 Unsharp masking, 3:383  
 Unsubtracted image, 3:383  
 Upper femora, 1:344t  
 Upper limb. *see also specific anatomy*  
   anatomy of, 1:98  
   joints of, 1:95t  
   trauma radiographs, 2:27-29  
 Upper thoracic vertebrae projections, 1:392t  
 Ureterocele, 2:200  
 Ureters  
   anatomy of, 2:195, 2:198  
   compression of, during urography, 2:212  
   cystoureterography of, 2:205  
   function of, 2:198  
   retrograde urography of, 2:226-227  
   sectional anatomy of, 3:158-161  
 Urethra  
   anatomy of, 2:195, 2:199  
   cystourethrography of  
     in females, 2:236-238  
     in males, 2:235  
   female, 2:199  
   male, 2:199  
   projections of  
     AP, 2:236-238  
     AP oblique, 2:235  
 Urinary bladder  
   anatomy of, 2:195, 2:198  
   sectional, 3:160-161, 3:164  
   capacity of, 2:198  
   carcinoma of, 2:200  
   cystography of  
     contraindications, 2:228  
     Urinary bladder—*cont'd*  
       cystography of—*cont'd*  
         contrast media for  
           description of, 2:228  
           injection of, 2:228  
         definition of, 2:205  
         indications, 2:228  
         injection equipment, 2:228  
         preliminary preparations, 2:228  
         retrograde, 2:228-229, 2:232  
       projections of  
         AP, 2:217  
         AP axial, 2:230-231  
         AP oblique, 2:232-233  
         chart for, 2:201  
         lateral, 2:234  
         PA axial, 2:230-231  
         in right or left position, 2:234  
         in RPO or LPO position, 2:232-233  
       sectional anatomy of, 3:160-161, 3:164  
 Urinary system  
   anatomy of, 2:195, 2:199  
   contrast studies of  
     nephrotomography, 2:202  
     patient preparation, 2:209  
   urography  
     adverse reactions to iodinated media, 2:208  
     antegrade, 2:203-204  
     excretory  
       contrast media, 2:206  
       history of, 2:206  
       ureteral compression during, 2:212  
     indications, 2:203  
     intestinal tract preparation, 2:208-209  
     intravenous, 2:203  
     motion control during, 2:211  
     percutaneous antegrade, 2:203  
     procedure, 2:211-212  
     radiation protection during, 2:213  
     respiration considerations, 2:212  
     retrograde  
       contrast media, 2:206-207  
       description of, 2:205  
       history of, 2:206  
       illustration of, 2:207  
       of pelvicalyceal system and ureters,  
       2:226-227  
     projections of  
       AP, 2:216-217  
       AP oblique, 2:218  
       chart for, 2:201  
       in dorsal decubitus position, 2:220  
       lateral, 2:219-220  
       overview, 2:194t  
       in right or left position, 2:219  
       in RPO and LPO positions, 2:218  
 Urine, 2:195  
 Urography  
   abdominal examination, 2:213  
   adverse reactions to iodinated media, 2:208  
   antegrade, 2:203-204  
   chart for, 2:201  
   equipment for, 2:210  
   excretory  
     contrast media, 2:206  
     history of, 2:206  
     radiation protection during, 2:213  
     ureteral compression during, 2:212  
   indications, 2:203  
   intestinal tract preparation, 2:208-209  
   intravenous, 3:315  
   contraindications, 2:213  
   description of, 2:203  
   indications, 2:213  
   procedure, 2:214-215  
   radiographs for, 2:215



Urography—*cont'd*  
 motion control during, 2:211  
 percutaneous antegrade, 2:203  
 procedure, 2:211-212  
 radiation protection during, 2:213  
 respiration considerations, 2:212  
 retrograde  
   contrast media, 2:206-207  
   description of, 2:205  
   history of, 2:206  
   illustration of, 2:207  
   patient preparation, 2:209  
   pelviccalyceal system and ureters evaluation, 2:226-227  
 Urolithiasis, 2:213  
 Uroradiology, 3:128  
 Useful patient dose, 3:353  
 Uterine fibroid, 2:259, 3:74  
 Uterine tubes  
   anatomy of, 2:253  
   obstruction of, 2:259  
 Uterus, 2:254  
 Uvula, 2:39, 2:52

## V

Vagina, 2:254, 3:160-161  
 Vaginography, 2:260, 2:262-263  
 Valdin method, 2:302  
 Valium. *see* Diazepam  
 Valsalva's maneuver  
   AP projection of, 2:59, 2:65  
   modified, 2:59  
   uses of, 2:52, 2:59  
 Valvular competence, 3:128  
 Varices, 3:128  
 Vascular system, 3:21-24  
 Vasovagal reaction, 2:7t  
 Veins  
   coronary, 3:23  
   definition of, 3:128  
   diagnostic ultrasound of, 3:450-451  
   function of, 3:21-22  
   pulmonary, 3:23  
 Velocity, of sound, 3:459  
 Venipuncture  
   complications associated with, 2:249  
   documentation, 2:249  
   infection control, 2:242  
   medications  
     administration of, 2:248  
     description of, 2:239-241t  
     preparation of, 2:243-244  
     reactions to, 2:249  
   needles and syringes for, 2:242-243  
   patient assessment, 2:242  
   patient education, 2:239  
   procedure  
     site preparation, 2:246  
     site selection, 2:244-245  
     venipuncture techniques, 2:246-248  
   professional and legal considerations, 2:239  
 Venogram, 3:26  
 Venography  
   central, 3:43-44  
   definition of, 3:128  
   hepatic, 3:45  
   inferior vena cava, 3:44  
   lower limb, 3:49, 3:78  
   renal, 3:46  
   superior vena cava, 3:43  
   upper limb, 3:47  
 Venotomy, 3:128  
 Ventricles  
   of brain, 3:4  
   definition of, 3:128  
   of heart, 3:22  
 Venules, 3:21, 3:128

Vermis, 3:2  
 Versed. *see* Midazolam hydrochloride  
 Vertebrae  
   anatomy of, 1:396  
   cervical  
     anatomy of, 1:394, 1:397-398  
     sectional, 3:137-138  
     curvature of, 1:395  
     entrance skin exposure for, 1:48t  
     Grandy method, 1:422-423  
     landmarks of, 1:62t  
     magnetic resonance imaging of, 3:404  
     mobile radiography projections of, 3:256-257, 3:296-297  
   operative radiology of, 3:279, 3:296-297  
   Ottomello method, 1:430-431  
   projections of  
     AP, 1:430-431  
     AP axial, 1:420-421  
     chart, 1:409  
     in hyperextension, 1:424  
     in hyperflexion, 1:424  
     lateral, 1:422-425  
     oblique, 1:486  
     overview, 1:392t  
     in right or left position, 1:422-425  
   sectional anatomy of, 3:137-138  
   surgical radiology of, 3:279  
   tomography of, 3:320t  
   trauma imaging  
     AP axial oblique projection, 2:14  
     AP axial projection, 2:13  
     dorsal decubitus, 2:11-12  
     lateral projection, 2:11-12  
   typical, 1:398-399  
 lumbar  
   anatomy of, 1:394, 1:402-403  
   sectional, 3:164  
   dual x-ray absorptiometry of, 3:516-518, 3:522  
   intervertebral foramina of, 1:403  
   landmarks of, 1:62t  
   magnetic resonance imaging of, 3:404  
   mobile radiography of, in operating room, 3:298-299  
   operating room imaging of, 3:280-281, 3:298-299  
   projections of  
     AP, 1:448-451  
     chart, 1:409  
     lateral, 1:452-453  
     oblique, 1:486  
     overview, 1:393t  
     PA, 1:448-451  
     in right or left position, 1:452-453  
   sectional anatomy of, 3:164  
   surgical radiology of, 3:280-281  
   tomography of, 3:321t  
   zygapophyseal joints of, 1:403  
 thoracic  
   anatomy of, 1:394, 1:400-401  
   sectional, 3:142-149  
   entrance skin exposure for, 1:48t  
   landmarks of, 1:62t  
   mobile radiography of, 3:298-299  
   operating room imaging of, 3:298-299  
   projections of  
     AP, 1:440-441  
     chart, 1:409  
     lateral, 1:442-444  
     oblique, 1:486  
     overview, 1:393t  
     in right or left position, 1:442-444  
     in supine position, 1:440  
     in upright position, 1:440  
   sectional anatomy of, 3:142-149  
   tomography of, 3:320t

Vertebrae—*cont'd*  
 thoracic—*cont'd*  
   trauma radiographs, 2:15  
   zygapophyseal joints of, 1:401  
 Vertebral arch  
   anatomy of, 1:396  
   projections of  
     AP axial, 1:432-433  
     AP axial oblique, 1:434  
     PA axial oblique, 1:435  
   in right and left head rotations, 1:434-435  
 Vertebral artery, 3:138, 3:141, 3:143  
 Vertebral canal, 1:396  
 Vertebral column  
   anatomy of, 1:394, 1:406t-407t  
   articulations of, 1:406  
   composition of, 1:394  
   curvature of, 1:395  
   functions of, 1:394  
   kyphotic curves of, 1:395  
   lordotic curves of, 1:395  
   pathology of, 1:408  
 Vertebral foramina, 1:396  
 Vertebral fractures, 3:496  
 Vertebral notches, 1:396  
 Vertebra prominens, 1:397  
 Vertical ray method, for contrast arthrography of knee, 1:586-587  
 Verticogsubmental projection  
   cranial base, 2:325  
   mandible, 2:390-391  
 Vesicoureteral reflux, 2:200  
 Vesiculography, 2:270-271  
 Vestibular folds, 2:53  
 Video tape recorder, 3:383  
 View  
   definition of, 1:85  
   projection and, differences between, 1:85  
 Viewbox, 1:7  
 View trace, 3:383  
 Villi, 2:123  
 Viral pneumonitis, 1:538  
 Visceral, 1:75  
 Vistaril. *see* Hydroxyzine hydrochloride  
 Vitamin D, 3:497  
 Vocal folds, 2:53  
 Voiding cystourethrogram, 3:208  
 Volumetric density, 3:530  
 Volvulus, 2:127  
 Vomer, 2:291  
 Voxel, 3:353  
**W**  
 Ward's triangle, 3:530  
 Washout, 3:486  
 Waters method  
   maxillary sinus, 2:414-415  
   modified, 2:362-363  
   ocular imaging, 2:347  
   open-mouth, 2:416-417  
   reverse, 2:26, 2:364-365  
   standard, 2:360-361  
 Wave, definition of, 3:459  
 Wedge filter, 3:569, 3:576  
 Weight-bearing method  
   calcaneus, 1:281  
   foot, 1:273-274  
   knee  
     in flexion position, 1:315  
     in standing position, 1:314  
   lower limb, 1:340-341  
   lumbar intervertebral disks, 1:476-477  
 Welin procedure, for double-contrast barium imaging of large intestine, 2:172-173  
 West Point method, for inferosuperior axial projection of shoulder girdle, 1:178-179

Wigby-Taylor method, for styloid process, 2:426  
 Wilms' tumor, 2:200, 3:185  
 Windows, 3:353  
 Wolf method, for imaging of superior stomach and distal esophagus, 2:154-155

**Wrist**  
 anatomy of, 1:91-92  
 articulations of, 1:96  
 contrast arthrography of, 1:590  
 projections for  
   AP, 1:123  
   AP oblique, 1:127  
   chart for, 1:98  
   lateral, 1:124-125  
   lateromedial, 1:124-125  
   overview, 1:90t  
   PA  
     general image, 1:122  
     with radial deviation, 1:129  
     with ulnar deviation, 1:128  
   PA oblique, 1:126

## X

Xenon-133  
 lung ventilation scan, 3:483  
 radiopharmaceutical use, 3:467t

Xiphisternal joint  
 anatomy of, 1:491t  
 description of, 1:492  
 Xiphoid process, 1:490  
 X-ray(s)  
   discovery of, 1:40  
   early injuries associated with, 1:40  
 X-ray beam, 1:30  
 X-ray grids, 1:21

## Z

Zenker's diverticulum, 2:127  
 Zonography  
   abdominal structures evaluated using, 3:315  
   definition of, 3:327  
 Zoom, 3:383  
 Z-scores, 3:507, 3:530  
 Zygapophyseal joints  
   anatomy of, 1:396, 1:406  
   cervical vertebrae, 1:399  
   lumbar vertebrae, 1:403  
   projections of  
     AP oblique, 1:445-447, 1:456-457  
     chart, 1:409  
     overview, 1:393t  
     PA oblique, 1:445-447, 1:458-459

Zygapophyseal joints—*cont'd*  
   positioning rotations for, 1:399t  
   in RAO and LAO positions, 1:445-447, 1:458-459  
   in recumbent position, 1:445-446  
   in RPO and LPO positions, 1:445-447, 1:456-457  
   thoracic vertebrae, 1:401  
 Zygomatic arch  
   description of, 2:291  
   May method, 2:376-377  
   modified Titterington method, 2:354  
   modified Towne method, 2:378-379  
   projections of  
     AP axial, 2:378-379  
     chart, 2:353  
     overview, 2:352t  
     submentovertical, 2:372-373  
     tangential, 2:353, 2:374-377  
 Zygomatic bones, 2:291  
 Zygomatic process, 2:286  
 Zygote, 2:255